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DESIGNING FOR MASS PRODUCTION

AN INTRODUCTION

BY

J. R. FAWCETT

B.Sc. Hons. (Lond.), A.M.I.Mech.E.

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PREFACE

The rapid increase in the number of light mechanical articles manufactured by Mass Production methods, many of which are sold for use by the general public, has led to a completely new technique in design. The product must be, not only mechanically sound, but capable of being economically produced by Mass Production methods and have an appearance which is distinctive and pleasing to the eye.

This departure from traditional methods has meant that many engineers have found themselves confronted with a state of affairs requiring a new *modus operandi*, whilst the man first entering the engineering industry finds that the textbooks which would have adequately catered for his theoretical needs a few years ago, do not include in their scope the principles of the new manufacturing technique.

The Author has, therefore, endeavoured to include in this book all that is essential for those interested in mass-produced products to carry out their work intelligently. It has been assumed that the reader is at least familiar with the ordinary workshop processes, and has a knowledge of machine drawing. The book will, however, be found quite suitable for both teachers and students in Production Engineering classes.

It is, of course, impossible in the compass of a small book such as this, to give an exhaustive account of all that is connected with designing for Mass Production. The aim has been to present the essential features as clearly as possible, care being taken to point out the advantages and limitations of the various methods and processes, so that the pitfalls that often trap the unwary may be avoided.

To increase the value of the book for reference purposes it has been carefully indexed, and information which is likely to be required frequently is tabulated in an appendix.

Several firms have kindly supplied blocks and illustrations

and acknowledgment has been made against each. The British Standards Institution has kindly given permission to reprint extracts from several British Standard Specifications. Expert advice and criticism has been freely tendered by so many authorities that it is impossible to mention them individually.

The Author has read every available book published in England and America which touches on his subject, and although he believes his method of treatment to be original, he wishes to acknowledge the help which he has received from them.

J. R. FAWCETT

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PROPERTIES OF MATERIALS

THE materials used in engineering to-day are in such variety that it is no easy matter for the designer to choose the most suitable one for his purpose. The more common materials have been improved and are available in new and more convenient forms, and new alloys giving special advantages for exacting duties have been developed, allowing advances to be made in design which would otherwise have been impossible. In designing for mass production, where often one-half or more of the direct cost of a part is attributable to materials, a comprehensive knowledge of their forms and properties is indispensable.

Every part of a machine has to fulfil one or more of the following functions—

1. Resist stresses of various kinds.
2. Resist abrasion.
3. Resist corrosion due to moisture or chemicals.
4. Act as a spring.
5. Resist deformation.
6. Flow under local pressure.
7. Reduce friction.

In addition to these considerations there may be others, such as weight, bulk, working temperature, appearance, electrical properties, etc., which also have to be taken into account. Any of these qualities may be required in a greater or lesser degree. Stresses may vary from 50 or more tons per in.^{2} to a negligible amount; and abrasion may be slight, such as that due to rubbing with another metal, or extreme, as that due to sand and grit, and so on.

The materials used in engineering include the metals, their alloys, and the other materials mentioned below.

1. *Ferrous (Iron Base) Metals*

   Cast iron.
   Steel.

2. *Non-ferrous Metals*

Zinc Lead Copper Aluminium Magnesium Nickel Tin	Used either pure or alloyed.*
Antimony Arsenic Beryllium Carbon Chromium Manganese Molybdenum Phosphorus Silicon Tungsten Vanadium	Used in small quantities as alloying elements.

3. *Non-metallic Materials*

   Plastics
   Wood.
   Leather.
   Asbestos, etc.

With the exceptions of copper and aluminium, metals are rarely used in the pure state, as it is found that the addition of quantities (often very small) of alloying elements greatly improves their mechanical and corrosion resistant qualities. The number of alloys available commercially is very great, although many of them have similar properties. A wide field of research is still open for the discovery of new alloys with exceptional properties and discoveries are constantly being made.

Choice of Material. The material chosen for any part should be the one which, having regard to the allowable first cost, will be the most economical in service. First cost is generally

* In approximate order of price (by weight).

fixed by the market price of the product, and in order to reduce this so as to obtain a reasonable profit margin, the tendency in production work is to have the material shaped to as near the finished size as possible, so that the cost of waste material and that of removing it are reduced to a minimum. As will be seen later, this also influences the design.

A material may have to combine one or more of the functions mentioned previously, the possible number of combinations being very great, and it is not possible to consider them in detail. The following shows the method of approach for two typical applications—

Function	*Materials*
To resist medium stress and corrosion due to contaminated water.	Stainless steel. Monel.
To resist low stress and corrosion due to atmosphere.	Brass. Aluminium. Nickel silver. Zinc alloy, etc.

It will generally be found that several materials are suitable and the final choice will depend on such factors as price, availability and suitability for manufacture on existing plant.

TESTING OF MATERIALS

Engineering materials are usually subjected to certain physical tests which are used as a means of checking if the material conforms to previously determined standards, of comparing one material with another, and as a basis for design.

The tests usually carried out are as follows.

Tensile Test. A prepared specimen is clamped in special jaws in a testing machine and stretched until it breaks. A drawing of the British Standard Tensile Test Specimen is given in Fig. 1. If the length of the specimen is measured carefully as it stretches, it is found that up to a certain load (the *elastic limit* or *limit of proportionality*) the stretch is proportional to the load. This load on the material must not be exceeded if the latter is to return to its original length when the load is removed. Materials with a high elastic limit are especially valuable for springs. As the stretching proceeds, the material hardens and so is able to resist the additional load without breaking. When the limit of resistance caused by the hardening of the metal is reached, the test piece suddenly stretches without any increase in load. This is called the *yield point*. A further load causes the piece to break. The percentage increase in length of the two broken parts placed together, over an

original standard length (usually 2 in.), is called the *elongation.* The elongation is greatest for ductile metals, and the percentage elongation is used as an indication of the ductility of a material.

Proof Stress. A modified tensile test, called a *proof test,* is sometimes carried out, particularly on non-ferrous metals and for parts which have to be highly stressed in service. A 0·1 per cent proof stress is defined as that stress at which the

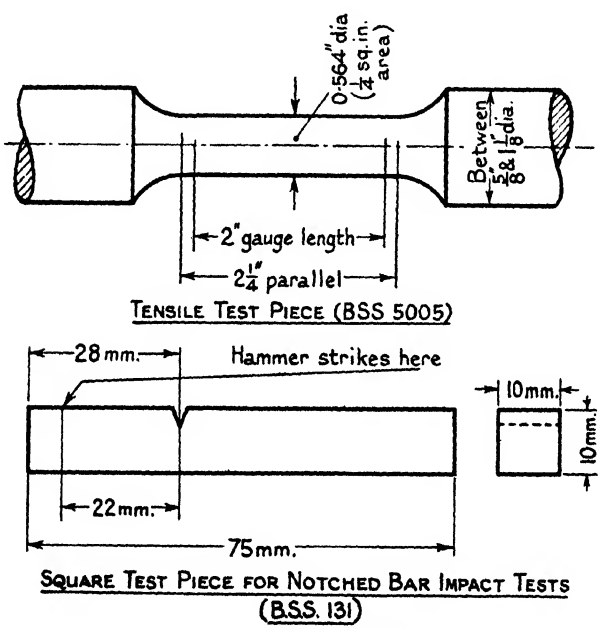


FIG. 1. TEST PIECES
British Standard

stress-strain curves deviate by 0·1 per cent of the gauge length from the straight line of proportionality.

Impact Test. This test is carried out in a special machine. The specimen, which is of the special shape shown in Fig. 1, with a vee notch cut in it, is struck by a heavy pendulum so as to break the specimen across the notch. The energy absorbed by the blow is measured in foot-pounds and is the *impact value* for that particular specimen. The "Izod" test is the test of this type most commonly used.

Hardness Tests. The usual hardness tests are carried out by indenting the surface of the metal with a diamond or a hard

steel ball under a given load, and measuring the size of the impression. This, converted to a suitable scale, is the hardness number of the material.

BRINELL HARDNESS TEST. This is carried out by forcing a hard steel ball of standard size into a smooth surface of the part under a standard load, and measuring the diameter of the depression with a microscope. From this is deduced the Brinell number. This test is not suitable for hardened steel.

ROCKWELL HARDNESS TEST. For this test a conical diamond or small steel ball is forced into the work first by a light load and then by a heavy load. The increase in the depth of the depression is shown on a scale as the hardness number.

FIRTH OR VICKERS DIAMOND PYRAMID HARDNESS TEST. This is similar to the Brinell test except that a diamond of pyramid shape is used and the measurement taken across the diagonals of the impression.

SCLEROSCOPE TEST. A weight is allowed to drop on the part from a given height. The height of rebound indicates the hardness.

Fatigue Tests. In the tensile and impact tests already described, the test piece is broken by a single application of the load. A fatigue test is carried out by applying an alternating or fluctuating load of less intensity than that required to cause immediate failure, and continuing to apply the load for a certain number of cycles, or until the specimen breaks. There are several types of machine used for fatigue tests, amongst them being the following—

WÖHLER MACHINE. The test piece is held in a rotating chuck and is loaded as a cantilever by a weight carried on ball bearings. As the test piece is rotated, each portion of the surface of the material is subjected to an equal tensile and compressive stress at each revolution. The machine is fitted with a revolution counter and a stopping device arranged to operate as soon as the test piece fractures.

HAIGH MACHINE. This is an electromagnetically operated machine which can be arranged to give the specimen an alternate push and pull, or a pulsating push or pull as may be desired.

Fatigue strength is usually taken for ferrous metals to be the maximum stress, alternately tensile and compressive, which the material will withstand without failure for 12 million cycles. In the case of tubular specimens, 6 million cycles are usually considered sufficient.

Interpretation of Tests and the Behaviour of Materials in Service. The stresses to which a part may be subjected may be classified under two main heads—

(1) Simple shear, tensile and compressive stress.

(2) Alternating or pulsating shear, compressive and tensile stresses.

In the first class are stresses which may induce failure by causing the material to yield and, if the load is increased, to fail, in the same way that a test piece fails in a tensile testing machine. This kind of failure is very rare in practice, except for brittle materials such as cast iron, for two reasons: firstly, because such loads are the easiest to calculate, and, if a part of a machine were subject to failure in this way, it would be noticed immediately and steps taken to rectify the weakness in succeeding machines; and secondly, with ductile materials, stresses due to misalignment or similar causes would be eliminated by the yielding rather than the breaking of the material. This property of adjustment is a valuable feature of the more ductile metals.

The most common types of stress met with on moving parts and machines are those of the second class, and it is such stresses that cause the majority of failures in practice, not only because they are difficult to predict, but also because the strength under a static load is little or no guide to the behaviour under pulsating loads or vibration. Small variations between apparently similar parts may mean the difference between long life and failure.

These failures, termed *fatigue* failures, are caused by repeated alternating or pulsating stresses, with an intensity below the yield point, which cause a crack to form in the surface of the material. The crack gradually extends until the area of sound metal left is insufficient to support the simple stresses, and ultimately the piece breaks. Fatigue cracks are less likely to develop in parts where the stresses are mainly compressive, and it is found that the higher the impact value of the material the more slowly the crack grows, so that not only is an opportunity given to discover that the part is cracked but also its life, even after the initial crack has formed, may be a reasonable one.

Simple examples of an alternating and compressive stress are a revolving shaft carrying gearing (such a shaft would also be liable to pulsating shear stress), the test piece in a Wöhler testing machine, and the connecting rod of a reciprocating engine.

With a pulsating stress there is usually an initial load with a superimposed pulsating load. Such a case would be the axle of a vehicle which carries the dead weight of the vehicle and is also subject to shocks due to irregularities in the road.

The behaviour under fatigue stresses varies with different materials. Ductile metals such as mild steel do not fail from fatigue unless they are subjected to practically equal tensile and compressive stresses. As this state of affairs rarely obtains in practice, fatigue failures of mild steel are very infrequent, and yielding is the first sign of an overload. High tensile steels, however, when under pulsatory stresses, are far more likely to develop a fatigue crack than to yield, and to use these materials to the best advantage the causes of fatigue failure must be thoroughly understood.

By experiment it has been found that the limiting fatigue stress for most ferrous materials lies between 0·46 and 0·53 of the ultimate stress. Thus an alloy steel with an ultimate strength of 60 tons per in.^{2} would have a fatigue limit of about $\pm$ 32 tons per in.^{2} In other words, it would support an alternate tensile and compressive stress of 32 tons per in.^{2} indefinitely. Fatigue limits vary for different methods of determination, but are found to be approximately 50 per cent of the ultimate strength whether the material is tough or brittle.

The following factors are those which have a great influence on the behaviour of a part subject to pulsating stresses—

1. Hardness of material.
2. Impact value of the material.
3. Shape.
4. Surface finish.
5. Corrosion.

The influence of the first two properties has already been explained. That of shape, though properly a question of design, can be briefly treated here.

It has been found that a sudden change of section in a part under stress causes a concentration of stress in that plane, and the effect of this concentration is far more pronounced in hard than it is in soft materials. If high tensile materials are to be used economically great care should be taken that all *stress-raisers*, as these causes of stress concentration have been termed, are eliminated or provided against. It is considered that one of the most important functions of the fatigue testing machine is the testing of actual parts, rather than the testing of materials. The following are some of the more common

stress-raisers, with some methods of minimizing their effects on parts subject to pulsating stresses.

HOLES. These will severely weaken a stressed part unless some means is taken of relieving the stress concentration. One method is to increase locally the section around the hole, while if this is impracticable, two grooves pressed into the metal either side of the hole at both ends, and at right angles to the axis of the stress, have been found very efficacious.

SHOULDERS. The maximum possible radius should be allowed at all changes of section. If a larger radius can be obtained by undercutting the shoulders, this should be done. Tapers are better than shoulders and should be used where possible. Isolated collars on a shaft do not cause appreciable stress concentration.

THREADS. An ordinary Whitworth thread will have a fatigue strength of about 75 per cent of the strength calculated on the area of the bottom of the thread. The radius and finish of the bottom of the thread are most important, and the plain portion of the shank should be reduced well below the bottom of the thread, and connected to the threaded portion by a substantial radius.

NOTCHES AND GROOVES. These must be avoided wherever possible. If inevitable, they should be treated in the same way as holes.

FORCE FITS. These appreciably reduce the fatigue strength, but it has been found that when ball or roller bearings have to be assembled in this way, the burnishing or rolling of the surface of the shaft before fitting the bearings restores the fatigue strength practically to normal.

Many fatigue cracks start at some surface fault, such as a tool mark, and thus the finish of a part may be of great imporance. A ground surface will give an increase of about 15 per cent in fatigue strength over a rough turned one, and polishing is even more effective. The original skin of the material should always be removed to a depth of at least $\frac{1}{16}$ in. Care should be taken as to the placing of inspectors' stamps and other marks.

Fatigue is accelerated by corrosion, and protection where necessary should be given from any likelihood of attack by moisture or acid. Galvanizing and plating may be employed for protecting parts which are exposed to the former, as non-stainless steel is particularly susceptible to fatigue from this cause.

Rigidity. Every body under stress is deformed proportionally to the intensity of the stress and in inverse proportion to the coefficient of elasticity or rigidity, according to the nature of the stress. If deformation is to be kept to within certain limits, this is accomplished by increasing the section of the body, thus lowering the stress, and using a material with a high coefficient of elasticity.

The moduli of elasticity and rigidity of the more common metals are given in Table I. The moduli of all steels are approximately the same, whilst those for cast iron are approximately one-third, and those for non-ferrous metals one-third to one-half those for steel. Thus rigidity cannot be increased by substituting high tensile steel for mild steel; but aluminium alloys are, weight for weight, more rigid than steel.

It is interesting to note the effect of stressing a 1 in. diameter high tensile steel bar 12 in. long in various ways, the maximum stress in each case being 50 tons per in.^{2}

Method of Stressing	Strain
In torsion . . . . . . (with one end fixed)	12° twist on 12 in.
In tension	$\frac{3}{64}$ in. increase in length (Energy absorbed: 224 ft.-lb.)
As a beam . . . . . . (supported at both ends and loaded in centre)	$\frac{1}{8}$ in. maximum deflection

It is clear that there are many instances in practice where such a comparatively large amount of deformation would be undesirable, and to overcome this the stress would have to be reduced, thus enabling a lower quality material to be used. These deflections must be allowed for where necessary in design, a simple case being that of a splined shaft with a part sliding on it. If the part is to slide while the shaft is under load, sufficient clearance must be left between the splines to allow for the twist of the shaft.

On parts where a certain amount of deformation is of no consequence, advantage may be taken of the elasticity of the steel to absorb shocks in the same way that a spring does, and so reduce the stresses on adjacent parts.

Application of Test Results. The usual tests carried out on a sample of steel give the following physical properties-

1. Ultimate stress (breaking stress).
2. Yield point.
3. Elongation.
4. Reduction of area.
5. Impact value.
6. Hardness value.

British Standard Test Pieces should, where possible, be taken from a $1\frac{1}{8}$ in. diameter bar. Allowance must be made for mass effect on larger and smaller sections, information on this being usually supplied by the steel maker.

For non-ferrous metals the tests are often reduced to—

1. Ultimate stress.
2. Proof stress.
3. Elongation.
4. Hardness.

In this book the figures have been further reduced to—

1. Ultimate stress.
2. Elongation.
3. Izod impact value (when obtainable).

These figures give sufficient information for comparative purposes, and if more detailed information is required, it should be obtained from the British Standard Specification concerned, or from the actual maker of the material it is intended to use.

The yield point may be taken as about 50 per cent of the ultimate stress for mild steels, increasing to about 85 per cent for an ultimate stress of 100 tons per in.^{2} The fatigue limit has already been stated as being between 46 per cent and 53 per cent of the ultimate stress, the latter figure applying to the high tensile steels.

Reduction of area is closely connected with elongation, and has independent significance only on a few materials. Hardness figures are given for unhardened materials as a criterion of machinability, too soft a material being as difficult to machine as one that is too hard. Hardness figures of sheet material are useful to ascertain the suitability to withstand bending operations.

Hardness tests (Rockwell or diamond pyramid) are made on work which has been heat treated to determine its efficacy,

whilst the ability to resist scratching with a smooth file is often considered sufficient for casehardened surfaces. The Izod impact value is a measure of the *toughness* of the material.

The application of test figures in forecasting how any specified material will behave under the conditions met with in service, has already been touched upon. A study of the results obtained from an actual material will show the inter-relationship of the various tests and the information they provide. Where stresses are not accurately known, test figures may be used as a basis of comparison between various materials, provided that they are not very dissimilar in properties. Two carbon steels might give the following results—

Carbon %	Ultimate Stress per In.^{2} Tons	Elongation %	Izod Ft.-lb.
0·3	30	30	100
1·0	70	2	2

The first material is soft, ductile, yields readily, can be cold worked, and has great resistance to fracture. The second material is hard and brittle, and although it has over twice the tensile strength of the 0·3 per cent carbon mild steel, it would be liable to crack and break in any ordinary service.

The effects of different heat treatments are as marked as those of different compositions. The test results for a $1\frac{3}{4}$ per cent nickel chrome steel which has been hardened in oil from 820° to 840° C., and tempered at various temperatures between 200° C. and 650° C., are shown in graphical form in Fig. 2 (p. 27). The graph indicates clearly the inter-relationship of the ultimate stress, elongation and Izod value, and is typical of similar graphs for many steels except in one particular. It will be seen that the Izod value dips sharply between 250° C. and 400° C., whilst little or no difference is noticed in the other curves. This behaviour, which is called *temper brittleness*, is peculiar to nickel-chromium steels; and it is found that when tempered between these temperatures they are unreliable in service. The impact test is particularly valuable in detecting faults of this kind which are practically impossible to detect by other means.

It will be noticed that the graphs for ultimate stress, yield point, and hardness are practically parallel, and it is found in

practice that a fairly reliable estimate of the ultimate strength can be obtained by a knowledge of the hardness. The elongation and reduction of area curves have also the same trend.

This steel has obviously very different properties when tempered at 200° C. from those it has when tempered at 650° C. At 200° C. the Brinell hardness is about 550, and the material is then suitable for gears where surface hardness is of more importance than resistance to shock. With such a hard steel the effect of stress concentrations would be serious. By tempering between 400° C. and 550° C. the ultimate stress is lowered to 70 to 90 tons per in.^{2} with a corresponding decrease in hardness; the reliability, as indicated by the impact value, increasing rapidly as the tempering temperature is increased. Further tempering to 650° C. gives a lower tensile strength than would be usual in practice with this type of steel, but leaves the material in a condition which may be useful for exceptional parts.

CHAPTER II

CAST IRONS AND STEELS

CAST IRON

Cast iron is a complex iron-carbon alloy containing, besides iron, 2·5–4 per cent of carbon, 1–4 per cent of silicon, and generally smaller percentages of manganese, phosphorus, and sulphur, the latter two elements being unavoidable impurities. It is usually produced by melting blast furnace pig iron and then pouring into moulds of the required shape. The character of the iron is influenced mainly by the amounts of carbon and silicon present, and whether the former is present as graphite or combined with iron in the form of pearlite or free cementite. The softer irons contain a larger proportion of graphite, have a grey coloured fracture, and are known as *grey cast irons.* A hard iron contains very little graphite and the fracture is white. A comparatively large percentage of silicon (3 per cent) gives a soft and free machining iron.

The compressive strength of cast iron is approximately four times its tensile strength, but the ratio is lower with the better and higher with the poorer irons. It has little or no ductility, and cannot be worked or forged either hot or cold. Plain cast iron is rather brittle and has no great resistance to shock, but is rigid. The graphite in the iron acts as a slight lubricant, and cast iron runs well with other metals. For use in certain exacting positions, e.g. motor car cylinder bores, no metal has been found to equal cast iron as a bearing material.

Cast iron may be poured into either sand or metal moulds, the former being the most usual. It is now possible to obtain sand castings which are accurate to within close limits, and with a surface which requires very little preparation prior to plating or enamelling. The use of metal moulds is not usual, the effect of the metal being to chill the iron and render it hard and white. However, by exercising special control, rods and simple sections for machining can be produced commercially from metal moulds.

Certain manufacturers in the U.S.A. have been successful in producing ordinary castings in metal moulds, but the process is a difficult one owing to the effect of the molten metal on the moulds.

Cast iron is one of the easiest metals to cast, and intricate shapes may be obtained without difficulty. The metal fills the mould well and takes a good sharp impression. For hollow sleeves, bushes and pipes it is found that by revolving the mould about an horizontal axis, whilst pouring the metal into it, very superior castings can be obtained. The process, known as the *centrifugal casting* process, is now extensively used.

Alloy Cast Irons. It has been found that by alloying certain metals, notably nickel, chromium and molybdenum, with cast iron, its properties are greatly enhanced.

One of the objections to ordinary cast iron is that the thin sections of a casting may become "chilled" or hardened, causing difficulty in machining, and that by making the iron soft enough to machine all over, a serious loss of strength results. By adding 1 to 2 per cent of nickel to the iron it is possible to eliminate chill and produce an iron which is of practically uniform hardness. This not only enables better castings to be made, but also reduces machining costs, so that the finished casting containing nickel may be cheaper than one that does not.

Cast irons containing larger amounts of alloying elements and requiring special care in their manufacture are comparatively expensive, but where they can be used instead of steel this may be offset by savings in machining and the cost of forging dies. Special cast irons may also be chosen instead of steel because of their greater suitability for certain purposes, notably wear resistance, and the greater latitude which the cast form gives the designer. Mention may be made of the "Meehanite" series of cast irons which are available in a number of grades with tensile strengths up to 30 tons per in.^{2}, moduli of elasticity up to 21×10^6 lb. per in.^{2} and hardness up to 600 Brinell. Research is being actively pursued, and the British Cast Iron Research Association are doing valuable research work on grey, white, and malleable cast irons, and ancillary materials.

Uses of Cast Iron. Cast iron is the cheapest constructional metal and its employment for large parts is often a necessity in order to keep the cost at an economic figure, but on smaller production work it has many competitors, as not only is the low strength/weight ratio of plain cast iron a disadvantage, but the cost of material in such cases is often a small proportion of the total. A valuable feature of cast iron, however, is that the bushing of bearings may often be dispensed

with, spindles running directly in the casting with excellent results.

Grey cast iron is almost always used for machine parts, two types being sufficient to cover most requirements. The first type (details of which are given in Table IV) is a close-grained material suitable for parts such as automobile and refrigerator compressor cylinders and similar components where a sound gas-tight casting is required. It is this type of iron which benefits most from the small nickel additions mentioned previously.

For less exacting work, such as typewriter frames, switchgear parts, pulleys, etc., a more common type of iron containing about 3 per cent silicon and 1 per cent phosphorus is used. This can be machined at high speeds (550 ft. per min. with tungsten carbide tools) and casts very well.

Table IV gives particulars of the plain cast irons just mentioned, and a representative range of alloy cast irons together with typical uses.

STEELS

Steel is the general name for all iron-base alloys containing between 0·05 per cent and 1·5 per cent of carbon. All steels are produced initially by casting, are malleable at suitable temperatures and when more than about 0·2 per cent of carbon is present may be hardened by quenching from a red heat. Small amounts of other elements are invariably present, usually sulphur, phosphorus, silicon, and manganese, but if not in excess they have little effect on the steel.

Alloy steels contain, in addition, one or more elements, notably nickel, chromium, vanadium, and molybdenum, which have important effects on the properties of the steel. Other alloy steels owe their properties to substantial amounts of manganese and silicon.

Carbon Steels

Carbon, or unalloyed steels, are usually classified according to their carbon content, upon which their properties are chiefly dependent. Steel with less than 0·2 per cent carbon cannot be hardened perceptibly by heat treatment, but as the carbon content is increased the capacity for hardening by quenching becomes more pronounced, until the commercial limit of 1·5 per cent carbon is reached. Steels for structural purposes usually have less than 0·5 per cent carbon, the higher carbon steels being used for tools, springs, etc.

High Carbon Steels. These contain between 0·6 per cent and 1·5 per cent of carbon and are obtainable in several qualities, the better ones being prepared with great care to ensure that all harmful impurities are excluded. These steels are always used in the hardened and tempered condition, especially for cutting tools (where no heat is generated), hammers, dies, and other tools.

They are often known as *carbon tool* or *cast steels*, but it should be noted that the usual method of supply is in the form of annealed hot rolled bars.

Leaded Steels. Steels containing a small proportion of lead (·15 to ·30 per cent) have been introduced and are claimed to reduce machining costs by 40 per cent due to more rapid machining and reduction of tool wear. The finish is better than that obtained with a similar unleaded steel and the amount of scrap is reduced. Leaded mild steels cost about 6 per cent more than the ordinary variety. "Ledloy" brand steels are supplied in free cutting, free cutting case hardening, mild steel, and carbon steels up to ·5- ·6 per cent C.; some alloy steels are also available. The effect of the lead on the physical properties of the steel is small and not sufficient to affect the design of moderately stressed parts.

Mass Effect. The size of a part made from steel has a pronounced effect on the stress the steel will withstand. A hard drawn 0·5 per cent carbon steel wire about $\frac{1}{32}$ in. diameter will have an ultimate tensile strength of between 150 and 200 tons per in.^{2}, while a bar of the same material 1 in. diameter would not have a tensile strength of more than 45 tons per in.^{2} Table IV shows clearly the effect of mass on the tensile strength of carbon and alloy steels.

Mass effect may be overcome to some extent by specifying a higher carbon content for more massive parts, and in B.S.En2 for Cold Worked Steel Bars, the specified carbon content is increased from 0·15 to 0·25 per cent for bars up to $1\frac{1}{4}$ in., to 0·25 to 0·30 per cent for $1\frac{1}{4}$ in. to $1\frac{3}{4}$ in. bars. One of the outstanding advantages of alloy steels is that the effect of mass is not so pronounced, though still not by any means negligible. Care should be taken when applying test figures of maximum stresses, etc., to large sections, to make adequate allowances for the increased size.

Mild and Medium Carbon Steels

Steels containing between 0·2 per cent and 0·35 per cent of

carbon are known as *mild* steels. They are obtainable in a large variety of forms, including castings, forgings, bar, sheet, etc. Mild steel may be worked both cold and hot; it machines readily, and may be welded by all the usual processes.

As mild steel is the cheapest commercial steel it is used extensively for parts where hardness or a high strength/weight ratio are not important. For machining purposes mild steel bar is produced by the cold drawing process, the bars being used *as drawn* for many parts. For parts subject to shock the bar should be normalized, as this has the effect of increasing the elongation and impact values considerably without seriously diminishing the tensile strength. Cold drawn mild steel is also improved by tempering up to 600° C. For parts where rigidity is of greater importance than ultimate strength, mild steel is not inferior to any other steel. It should not be casehardened unless the parts are massive.

Soft and Casehardening Mild Steels. Steel with less than 0·2 per cent carbon is soft and ductile and cannot be hardened by heat treatment. In sheet form it is used extensively for intricate pressings.

For parts which have to withstand wear this type of steel is casehardened (see page 27), the resultant product having an exceedingly hard skin (harder than that obtainable with alloy casehardening steels) and a tough ductile core. For lowly-stressed wearing parts this type of steel is unrivalled, both on account of low first cost and efficiency. These steels are most easily machined in the cold drawn condition and the machinability of forgings can be improved by quenching from 900° C.

Free-cutting Mild Steel. Mild steels, whether leaded or not, containing a comparatively large percentage of sulphur and phosphorus may be machined at much faster speeds than the regular material. For unimportant parts which can be machined at high speed, this material offers advantages; but as it tends to be brittle and is not so reliable as ordinary mild steel it should not be used for parts subject to shock.

The "Phoenix" Brand* free-cutting steels claim to be free from the defects usually found in these steels, and to exhibit the qualities of a good mild steel. Phoenix Brand steel may be obtained in the form of bar, sheet, stampings, wire, etc.

Medium Carbon Steels. These steels usually contain between 0·35 per cent to 0·45 per cent of carbon, although up to 0·55 per cent may be specified for special purposes. They are generally used in the form of forgings for fairly massive parts

* Made by the United Steel Co. Ltd.

either normalized or hardened and tempered, the latter treatment giving the better properties.

ALLOY STEELS

When elements other than carbon are added to carbon steel with the object of improving its properties, the resultant product is termed an *alloy steel.* The alloy steels of most importance in light engineering are the *high tensile* and *stainless* steels. The former have been developed to overcome the disadvantages of carbon steel for highly stressed parts, and to provide materials which can be more effectively heat treated. Stainless steels, originally used for cutlery, are now available with physical properties similar to many of the non-stainless varieties.

All alloy steels are used in the heat-treated condition.

Nickel Steels. The addition of even 1 per cent of nickel to a medium carbon steel appreciably increases the ductility and impact value for the same tensile strength and gives large parts a more uniform structure.

Nickel casehardening steel is first choice where a tougher core than is given by an unalloyed steel is required. By using a minimum nickel content of 3 per cent the double quench usually required for casehardening steels may be replaced by a single quench, with a corresponding minimizing of the risk of distortion. The useful limit of nickel in a casehardening steel is 5 per cent.

Oil-hardening nickel steels contain between 1 per cent and 3½ per cent nickel with a carbon content of 0·35 per cent to 0·45 per cent. The steels with the smaller nickel content are used in place of carbon steels for improving massive sections or where superior qualities are required at a moderate price. The higher nickel content steels are suitable for small and medium sized parts subject to shock, such as automobile axles, etc.

Low Chromium Steels. Steels containing chromium as the main alloying element are not so popular as those relying on nickel. A low chromium steel containing 1 per cent chromium and 0·35 to 0·45 per cent carbon is in fairly common use, it having the same physical properties as the corresponding 1 per cent nickel steel, but it machines more readily. Steel containing 1 per cent chromium and 1 per cent carbon is used where wear and pressure resisting qualities are required, as in ball and roller bearings.

Nickel-chrome Steels. The addition of about 1 per cent of chromium to nickel steels has the effect of increasing the uniformity of penetration of heat treatment, at the same time appreciably raising the ductility and impact values for a given tensile strength.

Nickel-chrome steels are made in equivalent casehardening and oil-hardening qualities to nickel steels, the corresponding nickel-chrome steels being suitable for more highly stressed parts and for large sections where the mass effect is considerable.

A steel with more than 3 per cent of nickel and 1 per cent chromium is *air-hardening*, that is, hardening is carried out by cooling fairly rapidly in the air. This type of steel not only gives a very high and uniform strength, but is valuable for parts which would be liable to warp if quenched in the usual way. Nickel-chrome steels are in some cases subject to *temper brittleness* when tempered at certain temperatures or cooled slowly from higher temperatures. Great care should be paid to the carrying out of the manufacturer's instructions when heat treating these steels.

Nickel-Chrome-Molybdenum Steels. The addition of molybdenum to nickel-chromium steels has the important effect of eliminating the temper brittleness just mentioned, further increasing the physical properties and reducing mass effect. These steels are capable of giving the best combination of properties of any steel, and an important feature is that they can be machined after heat treating to give a tensile strength of 100 tons per in.^{2}

Low Manganese Steel and Manganese-Molybdenum Steel. These steels contain respectively $1\frac{1}{2}$ per cent of manganese and $1\frac{1}{2}$ per cent manganese with $1\frac{1}{2}$ per cent molybdenum. They have higher tensile strengths than the corresponding carbon steel—this being obtained without lowering the ductility—while the cost is very little more.

Nitralloy Steels. These are special steels which are suitable for casehardening at a temperature of about 500° C. by the action of ammonia gas. This process is known as *nitriding.* The surface resulting from this treatment is harder than that produced by any other process, and is also very resistant to corrosion. Owing to the low temperature at which the hardening is carried out the risk of distortion is reduced to a minimum, thus allowing complicated parts to be treated. The hardness of the case introduces difficulties in design, and

care has to be taken to avoid sharp corners and other places from which cracks might commence.

Nitralloy steels are supplied in several grades with carbon contents ranging between 0·2 per cent and 0·5 per cent to suit the strength of core required. The parts are oil-hardened and tempered (above 500° C.) before the nitriding process. Any portions which do not require to be nitrided can be protected from the action of the ammonia gas by copper plating.

Stainless Steels. The stainless steels in general use are of two kinds known as *martensitic* and *austenitic*. The former usually contain between 12 per cent and 14 per cent of chromium, and from 0·1 per cent to 0·35 per cent of carbon, depending on the purpose for which they are to be used. The lower carbon types (also known as *stainless irons*) are adopted for general work where high strength is not required, and may be used for pressings, rivets, and machined parts. The 0·35 per cent carbon variety is used for knives and similar work, whilst a steel containing 18 per cent chromium and 2 per cent nickel is used for machined parts where superior corrosion-resisting properties are desirable, and particularly in contact with non-ferrous metals, or graphited packing.

Martensitic stainless steels must be hardened, tempered, and descaled or polished before the rust resisting properties are fully developed.

Austenitic stainless steels usually contain about 18 per cent of chromium and 8 per cent nickel. They cannot be hardened by heat treatment, but when cold worked harden appreciably. To obtain the maximum corrosion resistance it is necessary to quench the steel from about 1150° C. in oil or water: this also effectively softens the material. If the steel is for any reason heated above 500° C. it must afterwards be subjected to the above treatment, except in the case of the "weld decay free" steels, which should always be used for welding.

Austenitic stainless steels have a lower strength but superior corrosion-resisting properties to the martensitic type. They are used extensively for decorative and chemical work.

Stainless steels are somewhat difficult to machine owing to their work-hardening tendency, but there are now on the market proprietary free-cutting stainless steels which may be used where easy machining is of more importance than corrosion-resisting properties, although the latter are still sufficient for many purposes.

Spring Steels. A spring material should have a high elastic limit and a high elastic coefficient, or in the case of coil springs, a high modulus of rigidity. The material must also be uniformly sound and free from defects and inclusions. For important springs the material may be polished to ensure the removal of any surface cracks from which failure might start.

The more commonly used spring steels are as follows—

HARD DRAWN WIRE (piano or music wire) is obtainable in sizes from about 0·004 in. to 0·150 in. diameter, and is extensively used for the manufacture of small wire springs. The tensile strength of a 0·004 in. diameter wire would be between 150 and 200 tons per in.^{2}, but this can be varied by the manufacturer if desired. After forming, the springs are heated to about 250° C. for a few minutes, to relieve the strains set up during the forming process and to raise the elastic limit.

HARDENED AND TEMPERED WIRE may be used instead of hard drawn wire, especially where the forming to be carried out is severe.

HARDENED AND TEMPERED STRIP is used for making flat springs. It may be obtained bright or polished, and may be blanked, pierced, and bent slightly in suitable tempers.

CARBON STEEL WIRE suitable for the manufacture of coil and similar springs, should contain about 0·45 per cent to 0·75 per cent carbon for wire under $\frac{3}{16}$ in. diameter, and 0·9 per cent to 1·2 per cent carbon for wires larger than this. Wire should be made preferably by the acid process. Springs made from this wire are subsequently hardened and tempered in the usual way. A suitable temperature for tempering is 300° C.

SILICON-MANGANESE STEEL contains up to 2 per cent silicon and 1 per cent manganese, and has a carbon content of about 0·5 per cent. This steel has the advantage of an elastic limit of about 45 tons per in.^{2} compared with 35 tons per in.^{2} for a carbon steel in a similar condition, without being unduly expensive. Silicon-manganese steel is used extensively for leaf springs and also for highly stressed helical springs.

CHROME-VANADIUM STEEL is usually considered the best spring material available. The chromium and vanadium are present in the same proportions as for structural steel, but the carbon content is rather higher. The elastic limit is not less than 60 tons per in.^{2}, the figure depending on the heat treatment given. This steel is used for leaf springs and for important helical springs.

Chrome-Silicon Steel is similar in properties to chrome-vanadium steel and is chiefly used for leaf springs.

Commercial Forms of Steel

Steel is available in two general conditions, *cast* and *wrought*. Castings are made direct from the furnace, the molten metal being poured into suitably shaped moulds, and after any necessary machining and heat treatment, they are ready for use. By far the largest quantity of steel, however, is used in the wrought state, not only for convenience, but because of the better physical qualities of the steel.

The process of manufacture of wrought steels is briefly as follows. Cast ingots of the required chemical compositions are machined where necessary to remove surface defects, and then forged and rolled at a red heat into bars or sheets of the required size and shape. This hot working of the steel is of the greatest value in improving its qualities, and wrought steels are always more homogeneous and reliable than cast steels. The further treatment of the steel depends on the purpose for which it is intended.

Bars and Sections. Structural steel sections are always supplied in the hot rolled state, without heat treatment. Most alloy steels are supplied hot rolled in the form of round, square, and flat bars and sheets. Round bars for use in lathes are reeled to straighten them and remove some of the scale. Hot rolled bars are always covered with a scale of oxide, and the outer layers of the bar are liable to be decarbonized by the furnace gases, so a cut of a least $\frac{1}{16}$ in. deep should be taken to expose the good metal. Carbon and alloy steel bars may be obtained either "*as rolled*," *annealed*, *normalized*, or *hardened and tempered*, depending on the steel and the purpose for which it is to be put. Bar for making into forgings is ordered "as rolled," while steel which can be machined in the hardened and tempered condition should be so ordered. Many steels can now be finished by cold drawing through dies, the resultant bars being true to size within close limits and having a smooth bright surface. Drawn bars may be obtained in many shapes including standard rounds and hexagons. For important work cold drawn bar is normalized or tempered (see p. 26).

The demand for material which may be used without machining has led to the introduction of centreless ground bar, and all carbon and alloy steels may now be obtained in this form in many sizes to tolerances as fine as 0·00025 in. if necessary.

For spindles the surface finish is improved by specifying a polishing operation after centreless grinding.

Sheet and Strip Steels. Sheet and strip steel is supplied in the hot and cold rolled condition. Mild steel sheets are usually supplied in the cold rolled, close annealed condition with carbon contents giving materials suitable for deep drawing and ordinary work. The surface of this steel is clean, and the sheets are flattened after annealing and are very suitable for large pressings and panels. For heavier work such as frames, hot rolled sheet with a higher carbon content, and sometimes containing nickel, may be obtained.

Stainless steel sheet (usually austenitic) may be obtained in all sizes and with various finishes, including a highly polished one.

Material in strip form is most convenient for the manufacture of small and medium sized pressings. Strip may be obtained both hot and cold rolled, the former in gauges thicker than 20 S.W.G. (0·036 in.) and up to about 20 in. wide, depending on the thickness. Cold rolled strip is obtainable from 0·002 in. thick upwards, in widths up to 30 in. wide, depending on the thickness. Hot rolled strip has not the accuracy or finish of cold rolled strip, but it is good enough for many purposes and is substantially cheaper. Cold rolled strip is supplied in practically any carbon or alloy steel, the latter being used extensively for aircraft construction.

For press work cold rolled mild steel strip is supplied in the following tempers—

1. *Hard Bright.* For flat work, crisp shearing and easy punching, where no bending or drawing is involved, and maximum strength is required.
2. *Half Hard.* Will withstand 90° transverse bend.
3. *Medium Soft.* Will withstand a close transverse bend and a 90° longitudinal bend.
4. *Dead Soft.* For cupping and severe bending; able to bend in both directions flat on itself.
5. *Deep Drawing.*
6. *Bright Normalized.* For special purposes.

Strip metal, especially in the harder varieties, has a decided grain, and care must be taken that, when the corner radius is small, any bends are so arranged that they do not lie along it, whilst in some cases it may be convenient to lay out the parts diagonally across the grain, as in Fig. 30, p. 73.

Strip may be bought in cut lengths or in coils. Above $\frac{1}{16}$ in. thick it is preferable to purchase in lengths unless the work is not exacting or the material can be straightened before use. Strip, both hot and cold rolled, may be obtained with a sheared edge, which is generally preferable for press work, or with the edge left by the rolling process, which, though not so accurate in width, is useful where a rounded edge is required on the finished product.

Wire. Wire can be obtained made from mild steel, the spring steels already described, high tensile alloy steels, and the stainless steels. Mild steel wire is extensively used for rivets, thread rolled screws, and cold formed articles. It is obtainable in the round form and in many special shapes. Flat wire, with either square or semicircular edges, is a standard product. As all wire has, when produced, a naturally bright surface, its use enables finishing costs to be kept to a minimum, and in many cases it can be plated direct without any special surface preparation.

Tubes. Structural members which have to be light yet stiff can often be most conveniently made from tubes. Tubes can be made in mild, carbon and alloy steels and in a variety of shapes and sizes. They can be bent and manipulated by expanding, reducing and trapping, whilst jointing by welding and brazing presents little difficulty. The price of tubes on a weight basis is high and short hollow parts may often be made more cheaply by machining from the solid.

Forgings. From the process of forging parts under the blacksmith's hammer, methods suitable for quantity production have been developed by which parts can be forged very close to the finished shape, so that surplus material is practically eliminated and machining is only necessary on the more important mating surfaces.

The chief processes used are—

Drop Forging which is extensively used for production work and for which specially shaped steel dies, carried in a steam hammer or drop stamp, are used. A billet of red hot metal is placed between the dies and squeezed to shape by a succession of blows, it being subsequently trimmed and heat treated if necessary. Drop forgings can be made without great difficulty to within an accuracy of $\frac{1}{64}$ in., and for special purposes closer limits could be worked to. The shape of drop forgings is limited by the fact that they must be readily extractable from the dies.

Upsetting, which is used for making simple parts from bar stock. The most extensive use of this process is in the manufacture of bolts. The work is carried out in a special machine known as an *upsetting* or *heading machine.* The bar, previously heated to a red heat on one end, is gripped firmly between two dies, while a third die formed to the shape of the desired head is forced against the end of the bar. The machine is generally arranged so that the several operations to form a large head may be carried out in the same machine, the dies being arranged one above the other.

For headed pins, spindles, and similar parts, this process is very economical, and if centreless ground bar is used, subsequent machining may be reduced to a minimum. An important development of this process is to employ electrical resistance heating. The bar is put in the machine cold, gripped, and the forming die brought in contact with it. A low voltage current is then passed through the bar, which quickly brings it to forging heat. The current is then switched off and the forming die completes its stroke. If desired, the head may be given a final sizing blow in an ordinary press. The advantages of electrical heating are cleanliness and the absence of scale, enabling very accurate work to be performed and subsequent machining operations eliminated.

A variation of the upsetting process is used in connection with the manufacture of gear blanks, rings, and similar parts. For a solid gear blank the head is upset in the usual way, and sawn from off the bar while still hot. If the blank or ring is to have a hole in it, a bar the same size as the hole is used, and after upsetting, the centre of the ring, still joined to the bar, is punched out. It will be appreciated that the saving in material by using this method, as compared with other methods, may be considerable, while in addition the grain of the material is disposed to the best advantage.

Heat Treatment

The properties of steel may be altered considerably by heat treatment, and by suitable treatment the best qualities of the steel are developed. With the exception of the low carbon steels, practically all steels are used in the heat-treated condition.

Annealing or Softening. The steel is heated to slightly above its critical temperature and allowed to cool as slowly as possible. The critical temperature or *decalescence point* varies with each type of steel, and is the temperature at which it continues to

absorb heat without rising appreciably in temperature. This corresponds with important changes in the condition of the constituents of the steel.

CRITICAL TEMPERATURES FOR CARBON STEELS

Percentage Carbon	Temperature ° C.
0·3	830
0·6	765
0·9	740
1·1	820
1·2	860

The critical temperatures for steel with different carbon contents are given on the previous page, but it should be noted that other elements also influence the critical temperature. This information is usually supplied by the steel manufacturer.

Steel should not be heated more than a few degrees above the critical temperature as this may cause permanent injury to it.

After annealing, steel may be hammered, rolled, and otherwise cold worked, the effect of this being, as with other materials, to harden it, so that it may have to be annealed several times if the amount of cold work to be done is considerable.

Normalizing. When steel has been forged or cold worked, strains are set up in it which must be relieved by normalizing before machining or further heat treatment. Normalizing is carried out by heating the steel above its critical temperature and allowing it to cool in still air. It may be necessary to anneal high carbon steels subsequent to normalizing, before they are soft enough to machine.

Hardening. Steel is hardened by heating it above its critical temperature and cooling it quickly in oil, water, or air, depending on the type of the steel. The quicker the cooling takes place, the harder and more brittle does the steel become. Steel which has been hardened only is of no practical use, and is followed by a further heat treatment called *tempering*. The advantage of many alloy steels is that they will quench effectively in oil and in some cases air, and the risk of distortion due to the sudden cooling is reduced to a minimum.

Tempering. After hardening, steel is re-heated to a temperature depending on the purpose to which it is to be put. The higher this temperature is, the softer and more ductile the steel becomes, whilst its tensile strength diminishes. The

operation of tempering is a delicate one and needs care. It may be carried out in hot oil or molten salts, or in special furnaces with an air circulating fan to ensure an even temperature throughout the work. As tempering temperatures

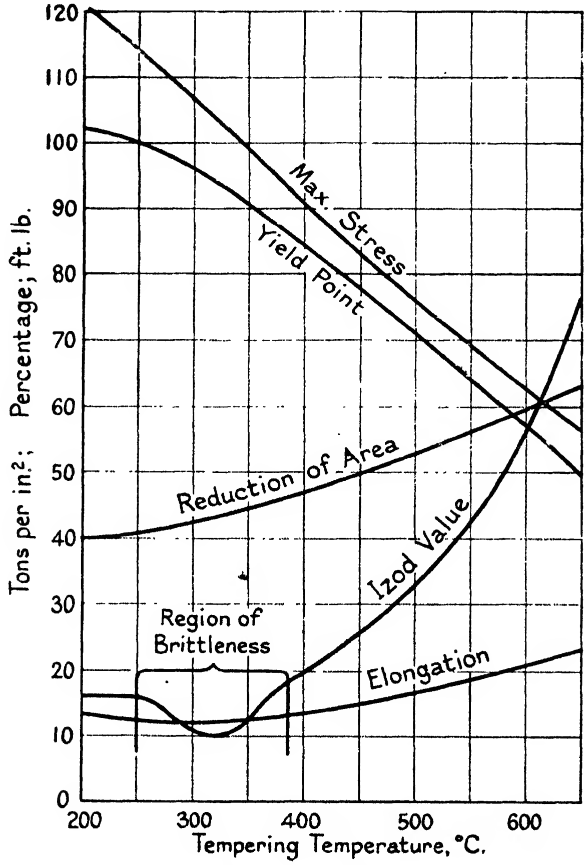


FIG. 2. EFFECT OF HEAT TREATMENT ON PROPERTIES OF $1\frac{3}{4}$ PER CENT NICKEL-CHROMIUM OIL-HARDENING STEEL

depend to some extent on the composition of the steel, it is best to follow the maker's instructions.

In Fig. 2 is reproduced a typical tempering chart, showing the effect on nickel-chrome steel of varying tempering temperatures. Not only is the wide range of properties obtainable by varying the temperature illustrated, but the danger of tempering without proper knowledge is also apparent. This steel must not be tempered between 250° C. and 400° C. and must be quenched in oil when tempered at a higher temperature.

Note. The term "tempered" should not be used instead of hardened, where the latter is meant.

Casehardening. It is impossible to harden steel with less than 0·2 per cent of carbon by heat treatment, but by heating steel above its critical temperature in contact with a carbonaceous material, such as bone dust or sodium cyanide, the outer layer of the part absorbs carbon, transforming it into a high carbon steel, the depth of the high carbon case depending on the length of time the processes are continued. This operation is known as *carburizing*. The effect of casehardening on a low carbon steel is to give, in effect, a dual purpose material, one with a tough core, which is resistant to shock, and an extremely hard case.

CARBURIZING. For larger articles carburizing is generally carried out by packing the articles in metal boxes with bone dust or one of the proprietary substances sold for the purpose, sealing the box with clay, and heating it in a furnace for the necessary length of time, after which the boxes are allowed to cool slowly before being opened. The usual depth of case is about $\frac{1}{32}$ in.

QUENCHING. To obtain the best results it is necessary to carry out two quenching operations. (See p. 18 for exceptions.) The first is to heat to the critical temperature of the core and quench, and the second, to heat to the critical temperature of the case and quench again. The work should then be tempered at about 100° C. to relieve stresses from the hardening operations.

CYANIDE HARDENING. For smaller and less important articles, a bath of molten sodium cyanide (sometimes mixed with other chemicals which have a beneficial action) is used as the carburizing agent. The parts are submerged in the cyanide for a few minutes, depending on the depth of case required and then quenched immediately into water, so completing the process. This method may be applied with advantage to gears of oil-hardening steel, which are heated in molten cyanide prior to quenching in oil. The hard case adds greatly to the life and load carrying capacity of the gears.

It is often necessary to leave soft part of the surface of a casehardened article such as a screw thread, or the area round a hole which has subsequently to be drilled. This may be effected in one of the following ways—

1. The portion to be protected from the carburizing action may be plated with a coating of copper about 0·001 in. thick.

2. A refractory paste may be spread over the part prior to carburizing. Such pastes are obtainable commercially.

3. About $\frac{1}{8}$ in. of metal may be left on the parts which are required to be soft, and this excess machined off after carburizing.

Selection and Use of Steels

The types of steel available are so many and their applications so diverse, that it is impossible to give more than the principles and a few typical examples.

For light engineering purposes steel is generally used in the wrought state in the form of bar, sheet, forgings, tube, wire, etc. If castings are required, cast and malleable irons are usually satisfactory for this purpose.

Mild steel is the cheapest wrought material in general use, and few non-ferrous metals can compare with it in strength. Nickel-chrome steels have a higher strength/weight ratio than the strongest aluminium alloy. Stainless steel, as used for valves, will resist hot exhaust gases at temperatures approaching red heat and yet retain a considerable tensile strength.

Steels may be grouped into three general classes—

1. Medium tensile strength (up to 40 tons per in.^{2})
2. High tensile steels (over 40 tons per in.^{2})
3. Stainless steels.

Their applications can be generally classed as—

1. Where low weight is not a primary consideration.
2. Where low weight is economically desirable or imperative.

The staple steel for parts included in the first class is mild steel. Non-ferrous metals are used, however, as bearing metals or where mild steel would be unsuitable on account of corrosion. For many wearing parts casehardened mild steel is satisfactory, although for small parts a 0·75 per cent carbon steel, hardened and tempered, is more economical. Where a wearing part is of an intricate nature, it may be more economical to use an oil- or air-hardening alloy steel and thus minimize the risk of excessive distortion in hardening.

For plain parts the mass effect of carbon steel may be exploited by water quenching steel containing 0·35 per cent to 0·4 per cent of carbon, the effect being to give a hard case and soft core, similar to casehardening, but at a much lower cost. Tempering should be carried out at 200° C. to relieve strains. The use of alloy steels for parts of this class can be

looked on as furnishing a margin available to the designer, should it be found that the stresses a part has to withstand have been underestimated.

The outstanding examples of the second class are the automobile and aeroplane, where the reduction of dead weight economically justifies the use of expensive materials. The tendency is to make all stressed steel aircraft components of alloy steel, as even small reductions of weight are important. On automobile work alloy steels are used more especially where stresses are necessarily high such as in the transmission and spring fittings.

As was explained on p. 9, it is impossible to increase rigidity to any appreciable extent by employing high tensile steels, and if this is imperative, low weight must be sacrificed. The weight of reciprocating parts may often be reduced by the employment of high tensile steels, the corresponding reduction of inertia and of the stresses in the surrounding parts enabling an overall saving of cost to be effected.

For high tensile parts subject to surface wear, the nickel and nickel-chrome casehardening steels are generally used, the oil-hardening steels being reserved for cases where there is little sliding or where soft white metal bearings can be employed.

Unless the stresses in a part are accurately known, it is better to specify one of the cheaper steels initially, and, if after putting into service the part is found unsatisfactory, the material may be changed to a better one, and so overcome the difficulty without having to re-design the machine.

If full advantage is to be taken of the properties of alloy steels, parts must be designed on the principles set out on p. 6, and heat treatment must be carried out with the greatest care. The concentrations of stress caused by changes of section increase with the harder materials, and if any doubt is felt the tempering should be carried out at as high a temperature as possible, the loss in tensile strength being more than compensated for by the reduced stress concentrations.

Although practically every material which is at all suitable has been tried for gearing, air-hardening nickel-chrome steel is generally favoured for high speed and heavily stressed gears. For heavy duty gears where this material would be too expensive, a casehardened nickel-chrome or 3 per cent nickel steel may be used, whilst for many purposes an oil-hardened 3 per cent nickel steel, heated in a cyanide bath, as described on p. 28, will be found satisfactory.

CHAPTER III

NON-FERROUS METALS AND PLASTICS

NON-FERROUS METALS

Aluminium. Aluminium is a white metal which combines reasonable strength with lightness, its density being only about one-third that of steel. It is not readily corroded, owing to the formation of a resistant film of oxide and is non-poisonous. Cold dilute acids do not attack it, but alkalis do so readily. Its conductivity both for heat and electricity is high, and this feature is of great practical importance.

Aluminium is used either in the pure state—commercial forms contain more than 98·5 per cent aluminium—or alloyed with various elements which have the effect of hardening and strengthening the metal without serious increase in density. Commercially pure aluminium is soft and ductile, and is drawn and pressed with ease. The fact that it will flow when cold is made use of in the manufacture of collapsible tubes.

The alloys of aluminium are more widely used for engineering purposes than the pure metal, and different alloys have their own specific uses. The ones most commonly used are those containing copper, zinc, and silicon, such alloys giving tensile strength up to 14 tons per in.^{2} in sheet form and 11 tons per in.^{2} when sand cast.

The standard casting alloy in this country is B.S.S. 3L5, details of which are given in Table IV, and this is suitable for most ordinary sand castings. Where greater strength and ductility are required, together with better casting properties, a silicon alloy such as BA/40J or BA/40D may be used. (The latter is made under a patented process.) The silicon alloys also show a marked resistance to corrosion, and may be exposed to steam without ill effects.

Pure aluminium, owing to its softness, is somewhat difficult to machine, and to overcome this difficulty a special screwing alloy (BA35, Table IV) which machines readily is available.

The development of the aeroplane has caused a great deal of research to be undertaken on aluminium and its alloys. The results have been so successful that alloys are now available with a tensile strength of 30 tons per in.^{2} and an elongation of 15 per cent. These alloys are comparatively expensive and

are only used where the economic value of the saving of weight outweighs the initial cost. Most of them are susceptible to heat treatment and only develop their best qualities after this has been carried out. For instance, duralumin, which is the most widely used alloy, has a tensile strength of about 15 tons per in.^{2} in the annealed state, but after heat treatment this is raised to 25 tons per in.^{2}

The heat treatment of aluminium alloys consists of heating them to a temperature of about 500° C. and quenching in water. This leaves the metal comparatively soft, and the full strength is brought out by soaking at a somewhat lower temperature. The exact treatment differs with each alloy, and with duralumin the second heat treatment takes place naturally at room temperature. Advantage of this is taken when using duralumin rivets, which are put in immediately after the first heat treatment, when they are soft enough to rivet, the metal then attaining its full strength in position.

Applications of Aluminium and its Alloys. PURE ALUMINIUM. Commercially pure aluminium is usually supplied as sheet and extruded sections Sheet aluminium is easily mabe drawn either with press tools or by spinning, and may nipulated readily. A large amount is used for food utensils, and it is often employed for manufacture of small covers and guards for machines. Sections are used mainly for ornamental work and fittings, where appearance is of greater importance than strength.

ALUMINIUM ALLOYS. Aluminium alloys are obtainable commercially as sheet, sections, forgings, sand and die castings, tubes, and wire. Table IV gives a list of the more common alloys, their physical properties and other particulars.

These alloys are used where weight and inertia must be kept low, and the extent to which they are used depends in large degree on economic considerations. For lowly stressed parts aluminium compares favourably with competitive materials, especially in cases where dimensions are governed by considerations other than that of strength. The cost of fabrication of aluminium is low: it can be machined at speeds of 1000 ft. per min. with tungsten carbide tools, and where die castings can be used machining is practically eliminated. The pleasing appearance and freedom from corrosion are also obvious advantages.

The aluminium alloys suitable for highly stressed parts are comparatively expensive and are largely used on aeroplane

work where reduction of weight is, of course, of great importance and their use is economically justified. Other uses are being developed, such as for parts of commercial vehicles, the weights of which are limited by law, or for parts of machines where inertia must be reduced to a minimum.

In automobile and aircraft work the applications of the various aluminium alloys are too numerous to mention. It is now a standard practice to employ aluminium alloys for crank cases, gear boxes, and pistons, whilst aluminium alloy cylinder heads, and connecting rods are also used. The success of aluminium alloy pistons is interesting, as not only does their lightness greatly reduce the inertia effect, but the high thermal conductivity may reduce the piston temperature by as much as 200° C., as compared with a cast-iron piston.

For domestic and other small appliances which have to be lifted and frequently moved about, aluminium, especially in the form of die castings, is invaluable.

Copper. Copper is a soft, ductile metal. In the pure state it has the highest electrical and thermal conductivities of any base metal, its nearest competitor being aluminium with a relative electrical conductivity of 62 per cent. Copper is resistant to corrosion and to weak organic acids and other chemicals, but, in common with its alloys should not be used in the presence of ammonia. It is used widely for electrical conductors.

HIGH CONDUCTIVITY (H.C.) COPPER is a 99·9 per cent pure copper made especially for electrical work. It is available in a wide variety of forms including sand castings, extruded sections, sheet, strip, wire, and tubing. The tensile strength and hardness of copper varies with the amount of cold work which is performed on it. Wire may be obtained with a tensile strength up to 30 tons per in.^{2}, with a corresponding elongation of 5 per cent.

Copper and its higher alloys are practically immune from corrosion fatigue, which is sometimes advantageous.

For non-electrical work copper is chiefly used in the form of its alloy, brass (see p. 34), which is not only cheaper, but has superior physical properties.

Beryllium Copper. This is an important alloy which can be hardened by a low temperature heat treatment to give a proof stress of 65 tons per in.^{2} It is expensive, but its unique properties make it very valuable for springs, for which purpose it is used in both strip and wire form. For electrical work it is to

be preferred to phosphor bronze because of its superior conductivity.

Zinc. Pure zinc is rarely used for machine parts, but it forms the basic metal for a series of valuable die casting alloys, which have a tensile strength of about 20 tons per in.^{2} and a melting-point of about 400° C. The low melting-point is a valuable property, as the life of the dies is naturally increased by a low working temperature. Details of these are given in Table IV.

The "B" alloy is the stronger and casts more readily but it shrinks about ·001 in. for each inch of length in the first few days after casting, and for greater accuracy the "A" alloy is used. This is given a stabilising heat treatment after casting. The type "B" must not be used at a temperature higher than 100°C. or it loses strength rapidly.

Die castings are made of zinc alloys wherever possible, as it is the most economical available material and is quite satisfactory except where exceptional lightness or strength is required.

Brass. The copper-zinc alloys containing from 55 per cent to 80 per cent of copper are known generally as *brass*, and are some of the most widely used and cheapest of the non-ferrous alloys. Brass is resistant to atmospheric corrosion and is easily machined and manipulated. By varying the proportion of copper and zinc and by adding small amounts of other elements, brasses can be made with tensile strengths varying between 18 and 35 tons per in.^{2}

The brasses fall into two groups; the first is suitable for cold working and may be cold rolled into sheets, drawn into wire and tubes, and pressed, while the second is more suitable for casting or hot working by rolling, extruding, and stamping. Brasses in this group also machine more easily.

The first group of brasses just mentioned contain usually between 63 per cent and 80 per cent of copper and are known as *alpha* brasses, owing to the metallurgical characteristics of the solid solution of copper and zinc. The most ductile alloy is that containing 70 per cent of copper and is known as *cartridge* brass. It is used for making articles which have to be severely cold worked, such as cartridge cases. With less than 63 per cent of copper another constituent known as *beta* brass is also formed in the solid solution, the effect of which is to harden the brass when cold but make it plastic over a wide

range of temperatures when hot. Such brasses are known as *alpha-beta* brasses.

Alpha brass is obtainable as sheet, wire, and tubing, and by varying the amount of cold work which is performed in the process of manufacture, different degrees of hardness can be obtained. In sheet form it is used for pressings of all kinds where rust would be undesirable and great strength is not required. The finish is good and it can be polished and plated easily.

For repetition work the alpha-beta brasses are generally used in the form of extruded bars and sections, and as castings, although the latter have been largely superseded by hot stampings, which are made by pressing pieces of extruded bar when hot between suitable dies.

Alpha-beta brasses are used for a large variety of machine work, as not only is there the advantage of freedom from corrosion, but machining may be done at extremely high speeds, and the great variety of extruded sections which are to be obtained may be gauged from the selection shown in Fig. 3.

Hot stampings are also widely used where the quantity of parts required warrants the expense of making the special dies. The photograph in Fig. 4 shows some typical examples.

HIGH TENSILE BRASS. Two alpha-beta brasses containing about 4 per cent of elements other than copper and zinc are of special interest owing to their high strength. These brasses are covered by B.S.250, 1001 and 1002, and are sometimes, though erroneously, called *manganese bronzes*.

Applications of Brass. A list of the types of brasses in common use is given in Table IV. For all ordinary turned work the 60/62 copper alloy with about 3 per cent of lead should be used. (The inclusion of lead gives the material its free machining properties but affects the ductility.) This is to be preferred to the 56–60 per cent copper type (B.S. 218), as it is not so brittle and gives a more reliable product.

When a part has to be machined and also bent or riveted, a brass with 62–64 per cent copper is recommended. If the riveting is not severe, about ½ per cent of lead may be incorporated.

For hot brass stampings an alloy containing 56–58 per cent copper with 1½ per cent lead is usual.

When selecting suitable materials from manufacturers' lists, many of which do not disclose the composition of the brasses produced, the type of brass can be selected from the

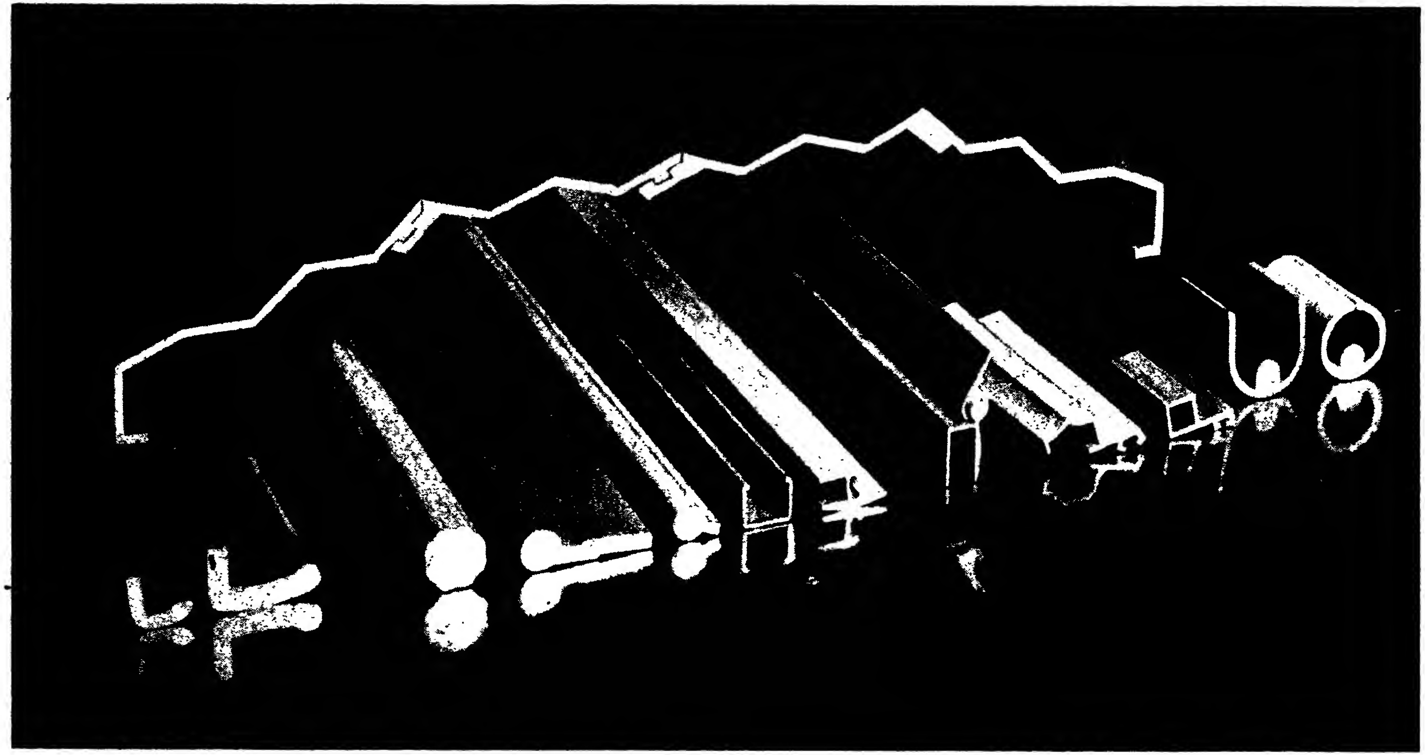


Fig. 3. Typical Brass and Copper Extruded Sections
Copper Development Association)

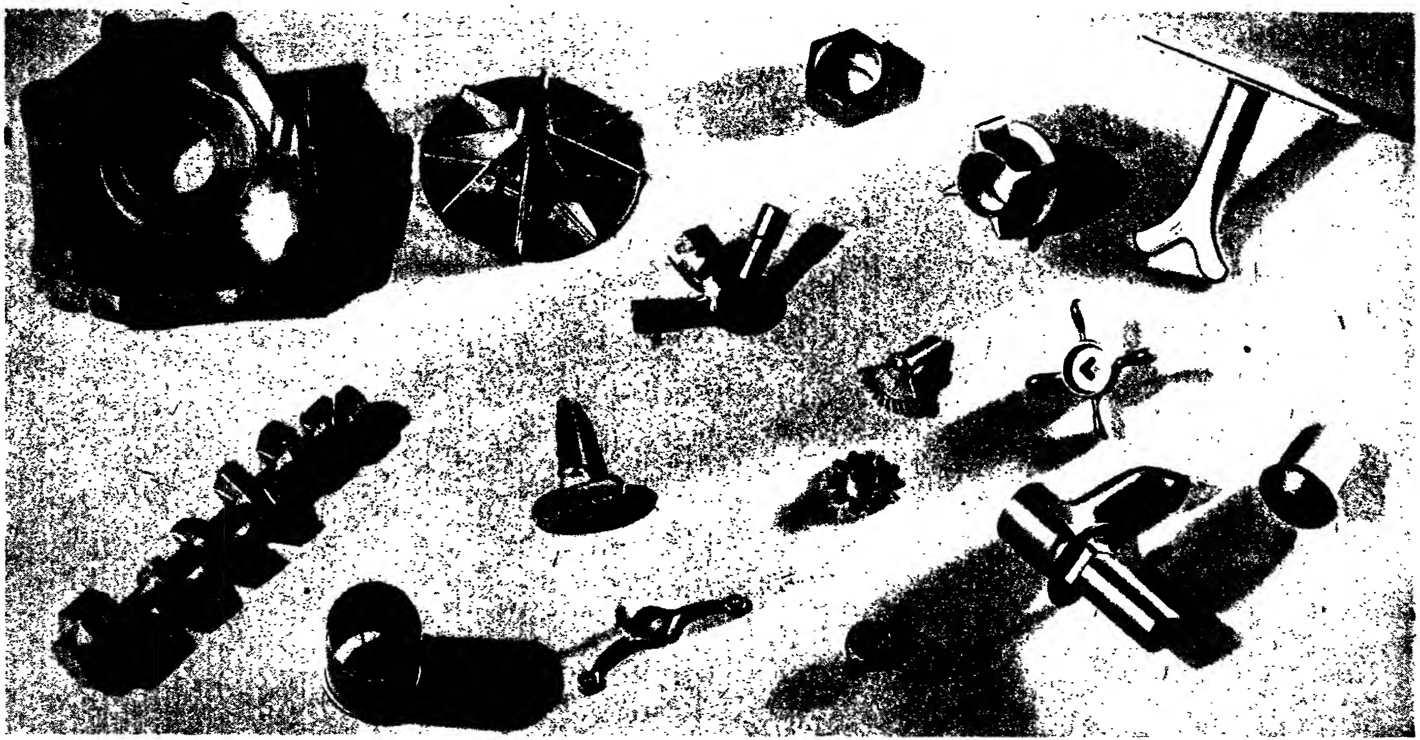


Fig. 4. Some Typical Hot Brass Stampings
(*Copper Development Association*)

published physical properties. These can be ascertained from Table IV.

The selection of brass sheet is best done in co-operation with the manufacturer.[5] There are four grades of sheet brass in general use (see Table IV). Cartridge Brass (B.S. 267: 1936), which is usually bought in the fully annealed condition, is used for deep drawn press work.

Brass to B.S. 266: 1936, is obtainable in a variety of tempers, the following being the tempers and physical tests they must withstand—

Temper	Test
Annealed	Bend double and close flat
Quarter Hard	Bend double and close flat
Half Hard	Bend double and close flat (up to 0·128 in. thick) Bend over radius equal to thickness (over 0·128 in. thick)
Hard	Bend through 90° over a radius equal to twice the thickness parallel with the direction of rolling

This brass is used for general press work and shallow drawn parts. Sheet to B.S. 265 is similar but not so ductile and is best confined to parts without sharp bends; it is slightly cheaper. For flat parts which have to be machined a similar brass with $1\frac{1}{2}\%$ lead is often used.

Brass pressings are liable to "season cracking," which causes them to disintegrate after a period, with undesirable repercussions on the manufacturer's reputation. To prevent this it is strongly recommended that all except the simplest of pressings should be heated to 250° C. for 1 hour after the final operation.

Brass is also available in the form of die castings, which are especially suitable for complicated parts required in quantities, but cannot compete with hot brass stampings for simple parts.

Nickel Silver (also called *German Silver*, or *Electrum*). This is an alloy containing copper, zinc and nickel, various qualities being available containing between about 10 per cent and 30 per cent nickel. The price depends on the quantity of nickel present, the cheaper grades being of a yellowish colour while the better grades resemble pure nickel in appearance.

It is used where a good appearance or resistance to corrosion is desirable, and is available as sheet (in various tempers, similar to brass), wire (used for electrical resistances), rod, and tube. Extruded varieties containing 8 to 18 per cent nickel are also available.

Bronzes. Bronze is the term generally applied to copper rich alloys which have superior physical qualities to brass. The most common are phosphor bronze and gunmetal which, in the cast form are used for bearings, pump bodies, pressure vessels, etc. Aluminium bronze is a high strength diecasting alloy. Phosphor bronze wire and strip is used for non-ferrous springs.

Cupro-Nickels and Nickel-Copper Alloys. Copper-nickel alloys containing various proportions of the two elements are occasionally used for special purposes. The alloy containing 80 per cent copper is extremely ductile and is used for bullet envelopes. The nickel gives high corrosion resistance, and alloys with 70 per cent copper are used for condenser tubes.

Monel. This alloy contains about 65 per cent nickel, is extremely resistant to corrosion, and has approximately the same physical strength as mild steel but retains its strength at far higher temperatures than does that metal.

Monel has many uses where conditions are such that other metals would fail due to corrosion, and may be used with confidence for parts which have to come into contact with dilute acids, sea water, dye stuffs, etc.

Special Bearing Metals. Special bearing metals may be divided into two classes, "Soft" and "Hard." The former type is used in conjunction with soft steel shafts, which it does not tend to score, and has the advantage of flowing under great pressure, so compensating for small inaccuracies in alignment.

For heavy duty Babbit metal containing about 90 per cent tin is used, but this is rather expensive and is often replaced by an alloy containing 25 per cent lead.

When a quantity of bearings is required, they may be die cast as half bearings and scraped, if necessary, to fit the shaft in position.

Where very heavy loads have to be borne, bearings made of mild steel, coated with lead bronze to a thickness of about $\frac{3}{64}$ in., may be used. The actual preparation of the lead bronze and the process of fusing it to the mild steel require care and experience if satisfactory results are to be obtained. These

bearings are used for the crankshaft bearings of aeroplanes and high-speed Diesel engines.

The hard bearing metals include phosphor bronze and gun metal. For ordinary bearings they are used in the form of bushes and should only be employed with hardened steel shafts, as they are liable to damage soft ones.

Porous oil retaining bearings are made from phosphor bronze powder by powder metallurgy. Further reference to these is made on page 109.

Forms of Non-ferrous Metals

Sand Castings. All non-ferrous metals may be obtained as sand castings either in the pure or alloyed state. For small production work sand castings have been largely superseded by die castings and hot pressings, but for larger work they are often inevitable, owing to the high cost of the dies required for the alternative processes.

Extruded Sections. These are formed by forcing the metal, which has been heated until it is plastic, through a suitably shaped die. Rods and tubes of practically any section may be extruded and then cut into convenient lengths. Sections produced by the extrusion process are sufficiently accurate for the majority of work. Greater accuracy can be obtained by drawing, after extruding, through suitable dies. The material may also be hardened in this way. Some examples of extruded sections are shown in Fig. 3, and the British Standard Tolerances are given in Table II.

The following metals and alloys may be obtained in the extruded form—

Aluminium and its alloys.
Copper.
Brass (56–65 per cent copper).
Aluminium bronze.
Manganese bronze.
Nickel silver (8–18 per cent nickel).
Lead.

Wire and Tubes. Most non-ferrous metals can be obtained in the form of wire and tube, which are produced by drawing cold through dies. The usual form is circular, but special shapes may be obtained if desired. By regulating the amount of cold work done various tempers may be obtained, from dead soft to a hard temper.

Cold Rolled Strip and Sheet. For the production of pressings practically all non-ferrous metals are obtained in the form of cold rolled strip. The finish is excellent and may be easily polished, or, if desired, strip may be purchased ready polished on one or both sides.

Sheet and strip may be obtained in various tempers, the standard ones usually being similar to those given for brass on p. 38. The British Standard Tolerances for thickness and width are given in Table III.

Hot Pressings. The process of hot pressing is confined to the alpha-beta brasses and nickel silver, both of which become very plastic at a red heat. A slug of metal, cut from an extruded bar, is pressed between two suitably shaped dies, and provided that the part can be extracted from the dies, very intricate shapes can be produced. The thickness of a section should not fall below about $\frac{1}{8}$ in., as the metal may chill and cause unsatisfactory work and damage to the dies. Examples are shown in Fig. 4.

Very small parts are better cold stamped from a 70/30 brass, which flows easily under pressure, the stamping being divided into stages with, if necessary, annealing after each.

Aluminium alloys such as duralumin and hiduminium R.R.59 may be drop forged in a similar manner to steel.

The essential difference between hot pressing and forging is that very intricate work may be produced by the former process with comparatively little pressure. Drop forgings require great pressure and the flow of the metal is limited.

Die Castings. Castings made in metal moulds are usually termed *die castings.* *Gravity die castings* are made by pouring the metal into the mould in the usual way, while in *pressure die casting* the metal is forced into the dies under pressure, making it possible to produce castings more speedily and with thinner sections.

The metals usually die cast are—

Aluminium alloys.	Zinc alloys.
Aluminium bronze.	Lead and tin base bearing metals.
Brass.	

Aluminium alloys are used where lightness is required, brass and aluminium bronze for strength, and zinc for die castings where no particular properties are needed. Lead base alloys are occasionally used for decorative work.

Die casting is usually carried out on special machines which carry the melting pot and pressure mechanism. The die is

generally in two main parts mounted on the machine, one part being connected to the metal injector and the other being movable, to allow of the die being opened and the casting removed. Cores are fitted in the die where necessary and are arranged so that they can be drawn out after casting. In cases where there is a likelihood of the casting sticking to the dies, ejector pins must be provided to expel it.

The design of parts intended to be die cast is not difficult provided that undercuts, which would prevent the part being ejected or which would necessitate the employment of loose pieces to make successfully, are avoided whenever possible. Taper must be allowed on all holes and bosses, etc., to facilitate withdrawal, the usual amount being a minimum of 0·010 in. per inch of length.

The making of complicated castings is often warranted by the fact that they take the place of several parts which would have to be made separately and fastened together if a die casting were not used.

ACCURACY. Although die castings can be made to an accuracy of 0·0015 in., it is wise to allow a fairly broad tolerance, and if fine limits are required, to enlist the co-operation of the manufacturer.

For dimensions dependent on only one part of the die, a tolerance of 0·0025 in. per inch may be held, but if this can be increased to 0·005 in. per inch or more, it will mean cheaper castings. For dimensions dependent on the position of two or more parts of the die while the casting is being poured, it is best to increase tolerances considerably as there are many factors which may cause irregularity. A tolerance of 0·010 in. should be regarded as a minimum, and this again should be increased if possible. It is a good plan to make the dies in the first place to as near the minimum metal limits as possible, so as to give a maximum life to the dies.

Other points which have to be considered when designing the dies are the provision of ejectors, and the runners for the entrance of the metal, both of which will affect the surface of the finished casting. It is usually advisable to mark on the drawing of the part any faces which are important so that ejector pins, etc., will not be used on them.

SIZE. Die castings may be made up to about 10 lb. in weight, though, of course, this figure will vary with the facilities at the disposal of each manufacturer. Pressure castings may be made with wall thickness down to $\frac{1}{16}$ in. on fairly small castings,

the minimum thickness for gravity castings being $\frac{1}{8}$ in. Both internal and external threads may be cast, but it is better to compare the cost of threading by ordinary processes before deciding to have the threads cast.

Inserts may be cast in position, provided that suitable means are available to hold them while casting.

NON-METALLIC MATERIALS

Plastics

The plastics are the most important non-metallic synthetic materials used by the engineer. The following are the most commonly used, with the trade names by which they are known in parenthesis—

(1) Casein (Erinoid, Lactoid).

(2) Cellulose acetate (Rhodoid, Celastoid, Cellestine, Erinofort, Non-flam Celluloid).

(3) Cellulose nitrate (Celluloid, Xylonite, Pyroxylin).

(4) Hard rubber (Ebonite, Vulcanite).

(5) Phenolic-formaldehyde resinoid (Bakelite, Elo).

(6) Urea-formaldehyde resinoid (Beetle, Pollopas).

(7) Laminated materials (Laminated Bakelite, Pressphan, Tufnol).

Plastics are of two main types, *thermo-plastic* and *thermo-setting*.

Thermo-plastics. These materials are softened by the application of moderate heat and set again on cooling. They are obtainable as rods, tubes, and sheet in a variety of colours, and the following are the more commonly used.

Casein turns and machines well and is a cheap material for knobs and similar articles. It should not be used where stability of dimensions is required, or in contact with moisture, which it absorbs.

Cellulose Acetate has good mechanical properties but is rather susceptible to moisture. By injecting whilst hot into dies on a suitable machine, simple articles may be made very rapidly.

Cellulose Nitrate is the most satisfactory of the thermo-plastics for many purposes. It is strong, resistant to moisture, and very stable, unless heated, when it is highly inflammable. Great care must be taken when working it, and special restrictions must be observed in workshops and stores where it is handled.

Hard Rubber is extensively used for its insulating properties, especially in the form of panels and machined parts. It can be moulded, but for this purpose it has been largely superseded by the resinoids. It is tough and stable, but tends to flow under pressure, such as that produced by a tight nut and bolt.

Thermo-setting Plastics. These are extensively employed for quantity production in the form of mouldings. The resinoids which form the bases of these plastics have the property of softening under heat and then hardening into an inert mass. After this change has taken place, further moderate heat has no effect. For moulding purposes the resinoid is mixed with a dye and a filler, usually wood flour, but asbestos flour and fabric are also used. The resultant mouldings have good insulating properties and tensile strengths of about 2–3 tons per in.^{2} The density is about half that of aluminium. The material is slightly brittle, but unless a severe blow is received, trouble from this cause is rarely experienced.

Phenol-Formaldehyde Resinoids, of which bakelite is the best known example, are the most extensively used materials for mechanical and electrical mouldings. The price is reasonable, moulding is easily carried out, and the mechanical and electrical properties are good enough for all ordinary purposes. The most satisfactory colours are black and brown. For simple parts, an addition of pieces of fabric to the material imparts to the mouldings good shock-resisting properties.

Urea-Formaldehyde Resinoids are similar in their applications to the phenol resinoids just described. They are, however, available in a wide range of colours, and being odourless and tasteless are ideal for food containers. The price is somewhat higher than for the phenol type, and their use for mechanical work is therefore limited.

Laminated Materials. These consist of laminations of paper or fabric which have been impregnated with a resinoid and subjected to heat and pressure. Owing to their insulating properties, the thinner kinds are used for electrical apparatus, and sheets up to about $\frac{3}{32}$ in. may be blanked and pierced with ordinary press tools. Above this thickness the sheet must be sawn. Suitable varieties are available for the manufacture of gears which are machined out of sheet of suitable thickness and are very satisfactory where a silent drive is concerned. Owing to the high strength/weight ratio, and resistance to the action of chemicals, this material may be used as a constructional material where the expense is warranted.

Laminated sheets may be obtained with a decorative finish, making them suitable for panels, etc.

Fibre. Fibre is made in the form of sheets from $\frac{1}{64}$ in. thick upwards, tube and rod, the base material usually being paper. Fibre is rather softer than phenolic bound materials but may be used for similar purposes. Fibre washers are used extensively for making petrol-tight points.

Moulding

The process of moulding is usually carried out in hardened steel moulds which are subjected to a pressure of about 2 000 lb. per in.^{2} between heated platens in a suitable press. The mouldings faithfully reproduce the surface of the mould, which is usually highly polished, the polish improving with use. The accuracy of the mouldings depends, of course, to a large extent on the initial accuracy of the mould. Dimensions which are not affected by the flash line of the mould (see Fig. 5) may be held to about 0·005 in., but those which are may vary from moulding to moulding and should not be relied on to be more accurate than 0·015 in. If greater accuracy is required, special care is necessary in moulding, with possible increase in price.

Holes perpendicular to the parting line are easily moulded, but cross holes, unless of such a size that the core pins are strong enough to withstand the pressure,are best drilled in.

Large threads may be moulded in easily and small threads under $\frac{1}{8}$ in. diameter may be tapped. Larger threads and ones which are to be used frequently are formed in brass inserts which are moulded into the material, pins being provided in the mould to position them. Inserts are cheaply made on automatic machines, either from hexagon bar, grooved to provide a key, or from round bar knurled for the same purpose. Countersunk headed screws can be used for male threads.

Besides inserts for threads, it is often convenient to mould in other metal parts to eliminate subsequent operations. The portion actually moulded in should be formed to provide an adequate key. Wires for electrical connections can also be moulded in, but where there is more than one, they should be covered to prevent short circuits.

It will be found that the moulding compound tends to creep

round the base faces of the inserts, and care should be taken that this does not cause trouble later.

In order to illustrate the principles, a simple mould, with the moulding in position, is shown in Fig. 5. The method of operation is as follows. The inserts and loose piece are placed in position, a weighed quantity of moulding compound poured into the bottom die and the top die placed in position. The

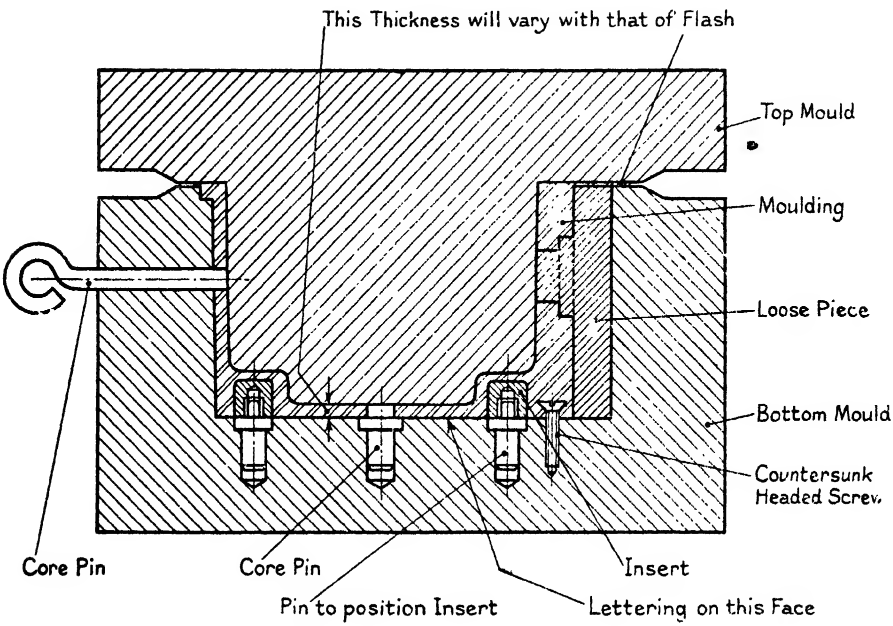


FIG. 5. MOULD FOR THERMO-SETTING PLASTICS

complete die is then placed in the press where the specified pressure and heat are applied. The pressure is then released, the die removed from the press, and the moulding ejected whilst still hot. It will be found that the excess moulding compound has been squeezed out as a flash, which prevents the top die from going right home, thus causing the dimensional variations previously mentioned. The large side hole is taken care of by the loose piece and can be moulded in satisfactorily. The small side hole would probably cause trouble owing to the small cores breaking. It would also be unsatisfactory to put inserts in this position. Any lettering should be put on the bottom of the cavity of the lower die. A small amount of taper is required on the sides of the moulding to allow the top

die to be withdrawn and the moulding ejected. A minimum figure is 0·005 in. per inch on diameter, but a larger amount should be allowed where possible.

It is wise to seek the co-operation of the moulding manufacturer when designing a moulded part, as it is difficult to appreciate the possibilities and limitations of the process without practical experience.

CHAPTER IV

MANUFACTURING PROCESSES

THE manufacturing processes commonly used in light engineering may be classified into the following—

1. *Machine Work.* Material in the form of bars, castings, forgings, etc., is cut to shape by means of machine tools.
2. *Press Work.* Sheet and wire material is cut and formed to shape.
3. *Jointing.* Metal parts are joined together by welding, soldering, etc.
4. *Finishing.* Surfaces are given a suitable protective or decorative finish.

It is essential that the designer of parts intended to be made in quantities should have a wide acquaintance with these processes, which are treated in detail in this chapter.

MACHINE WORK

The principal machining processes include the following—

Turning. The process of turning is carried out on machines known as *lathes*, which have been developed in many forms and sizes to deal with the large variety of work produced by this method. Lathes, as a class, represent the most important group of machine tools, and in conjunction with the cylindrical grinding machine are the most economical means of producing accurate work.

The usual types of lathe which are employed in light engineering are as follows—

1. *Engine Lathes.*
2. *Turret Lathes*, which include—
    - (*a*) Capstan lathes.
    - (*b*) Automatic screw machines (with one to six spindles).
    - (*c*) Automatic turret lathes.
3. *Centre Lathes*, which include—
    - (*a*) Multi-cut lathes.
    - (*b*) Automatic multi-cut lathes.

ENGINE LATHES. Any class of turning can be carried out on this type of lathe, an illustration of which is shown in Fig. 6, and these machines are used extensively in Tool Rooms owing to

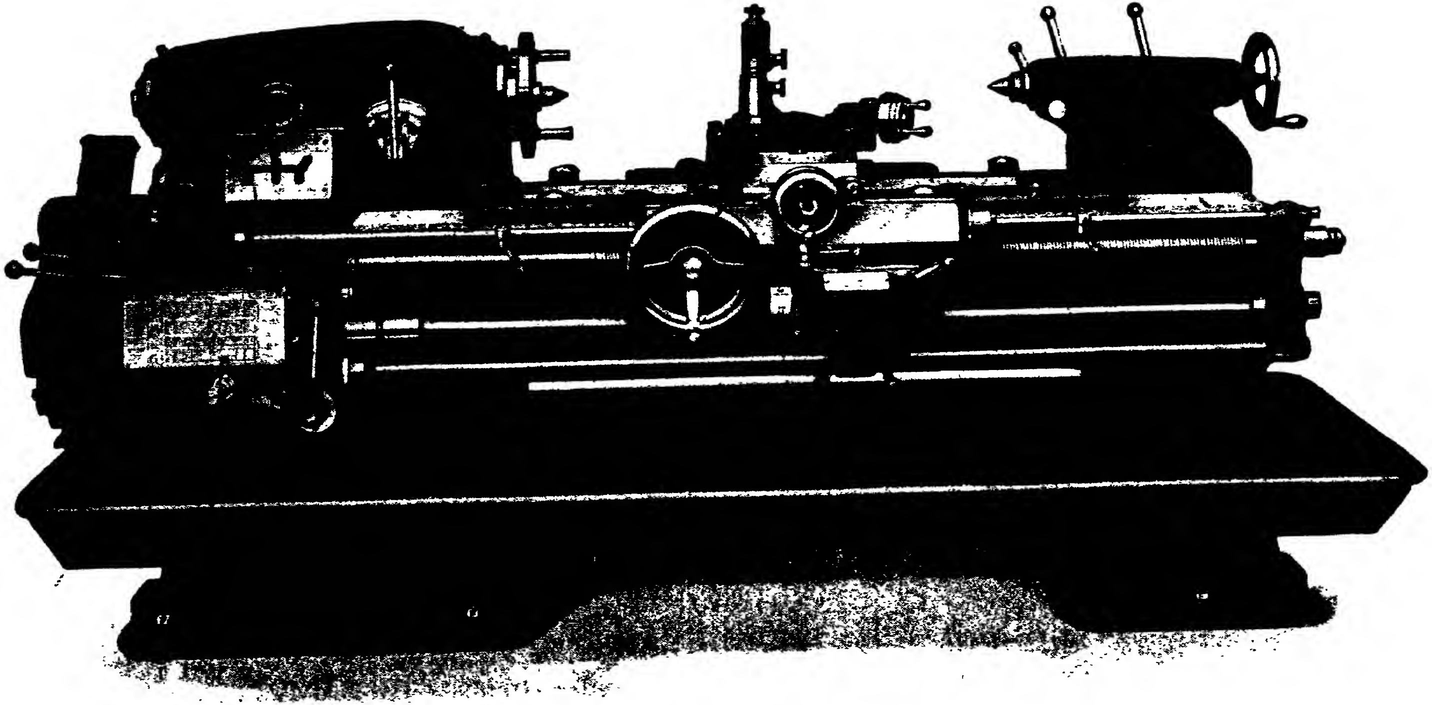


FIG. 6. LANG ENGINE LATHE
(Associated British Machine Tool Makers Ltd.)

their simplicity and the versitility of the tooling arrangements. The engine lathe is rarely used on production work as it is necessary to remove each tool from the machine before being able to use the next one.

TURRET LATHES. Once the tools have been set correctly, piece after piece may be produced on this class of lathe, until, by wear or accident, a tool needs to be sharpened or replaced. The use of these machines is usually justified whenever there are more than a dozen of a part to manufacture, and consequently they are the most commonly used type for production work.

Although the arrangement of these machines varies widely from make to make and from type to type, the basic principles, as they affect the design of components to be made, remain the same.

The tools are carried so that they may be presented in turn to the work. In the case of single spindle machines, the tools are usually carried in a revolving turret with four or six stations. At each station the turret is advanced to the work, the operation performed, the turret withdrawn, and then indexed to the next station.

Fig. 7 shows a capstan lathe tooled up for producing a screwed spindle.

Multi-spindle automatic machines are usually arranged so that the spindles are indexed and the work is presented in turn to each set of tools. The advantage of these machines is that as each operation is proceeding simultaneously, though on a different piece, the time required for each piece is only that for the longest single operation.

The designing of parts to be made on turret lathes requires little special care, but costs may often be reduced if attention is paid to the following points.

1. It should be possible to use tools sturdy enough to take economical cuts.

2. The work should be strong enough to resist the pressure of the cutting tools.

3. Holes should be largest at the mouth.

4. External surfaces should not have a small diameter between two larger ones unless it is comparatively short.

5. Long tapers should be avoided.

Turret lathes may be used to deal with material in several forms, the chucking arrangements differing for each.

Bar material is gripped in a collet chuck and fed forward as required, each piece as finished being cut off and the next piece proceeded with until the bar is used up.

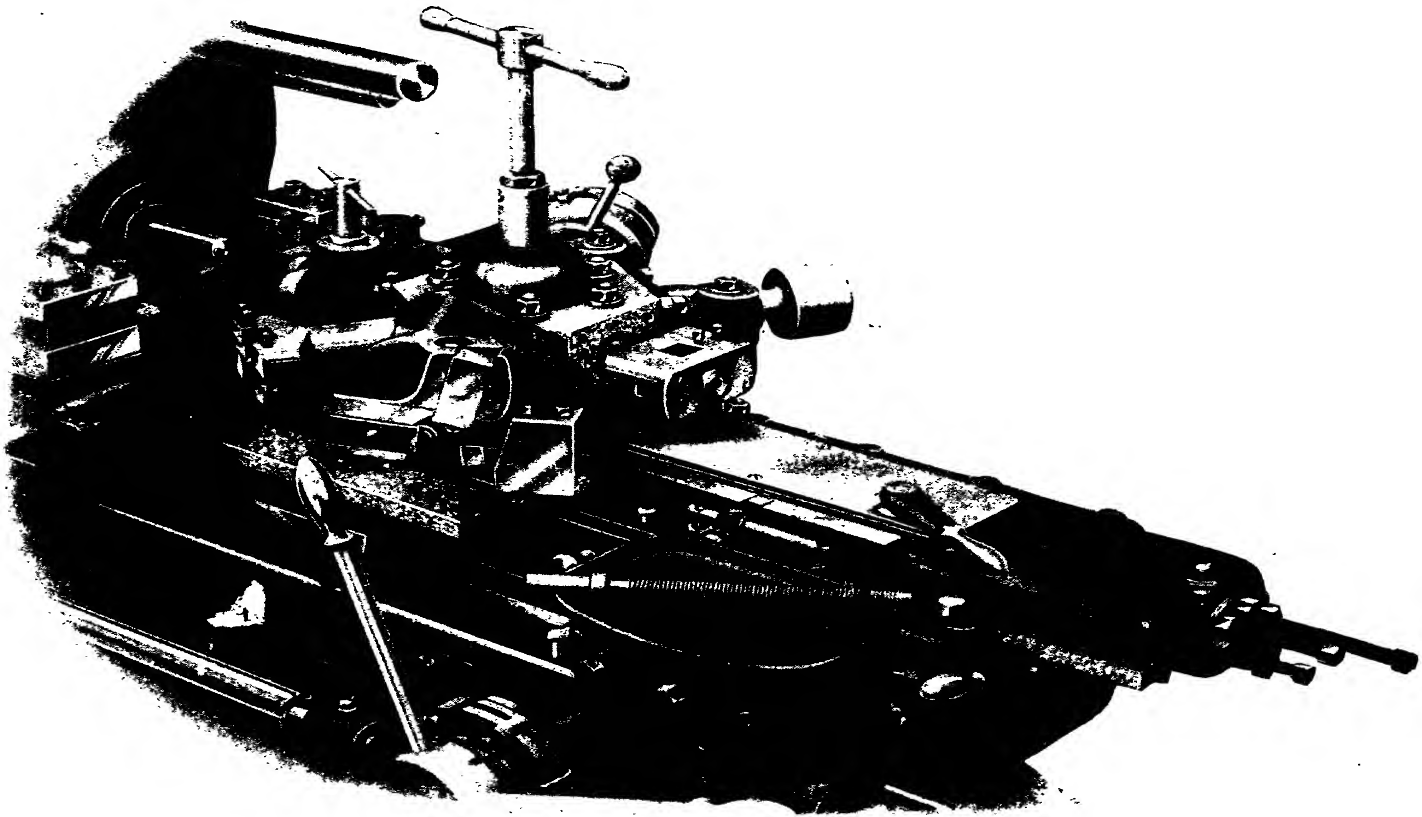


FIG. 7. CLOSE-UP OF WARD CAPSTAN LATHE
Showing tooling arrangements
(*Associated British Machine Tool Makers Ltd.*)

The methods employed in machining a simple piece on a capstan or automatic lathe from bar material are shown diagrammatically in Fig. 8. The successive stages are as follows—

Operation 1. Feed material forward to stop. (The end of the bar has been chamfered while making the preceding piece.)

Operation 2. Turn outside and drill hole for thread. The turning tool is of the "roller box" type, the pressure from the turning being taken by two rollers which revolve on the turned portion slightly behind the tool. By this means it is possible to obtain accurate work irrespective of the condition of the machine. A twist drill is held in the same holder and drills the hole for the thread simultaneously.

Operation 3. Turn chamfers and form nose of bar ready for next piece. A special form tool is necessary for this operation.

Operation 4. Knurl and drill small hole. Two rolls with multi-start helical grooves, one left-hand and the other right-hand, form the diamond shaped knurl. The small hole is drilled simultaneously.

Operation 5. Recess for thread. This recess is put to give a clear end for the thread. The small size of the tool will be noticed, and this operation will be a troublesome one. The piece should be designed, if possible, so that this recess is unnecessary.

Operation 6. Ream small hole. This operation is necessary to ensure that the hole shall be within the limits specified. Drills cannot be relied on to produce consistently accurate holes.

Operation 7. This operation necessitates reversing the direction of rotation of the spindle after tapping, in order to allow of the withdrawal of the tap.

Operation 8. Part off. The finished piece is cut off. It is difficult to ensure that the face of X will be flat, and if this is imperative it will be necessary to true the face on another machine. A note should always be made on the drawing for parts similar to this, as to the importance or otherwise of the face corresponding to X.

Parts which are supplied in the form of forgings, castings, or cut pieces are usually held in a chuck or, if this is inconvenient, a special fixture. Multi-spindle automatic lathes which are adopted for work of this type have one station reserved for chucking and unchucking the work, an operation usually performed by hand. This reduces by one the number of stations available for machining operations.

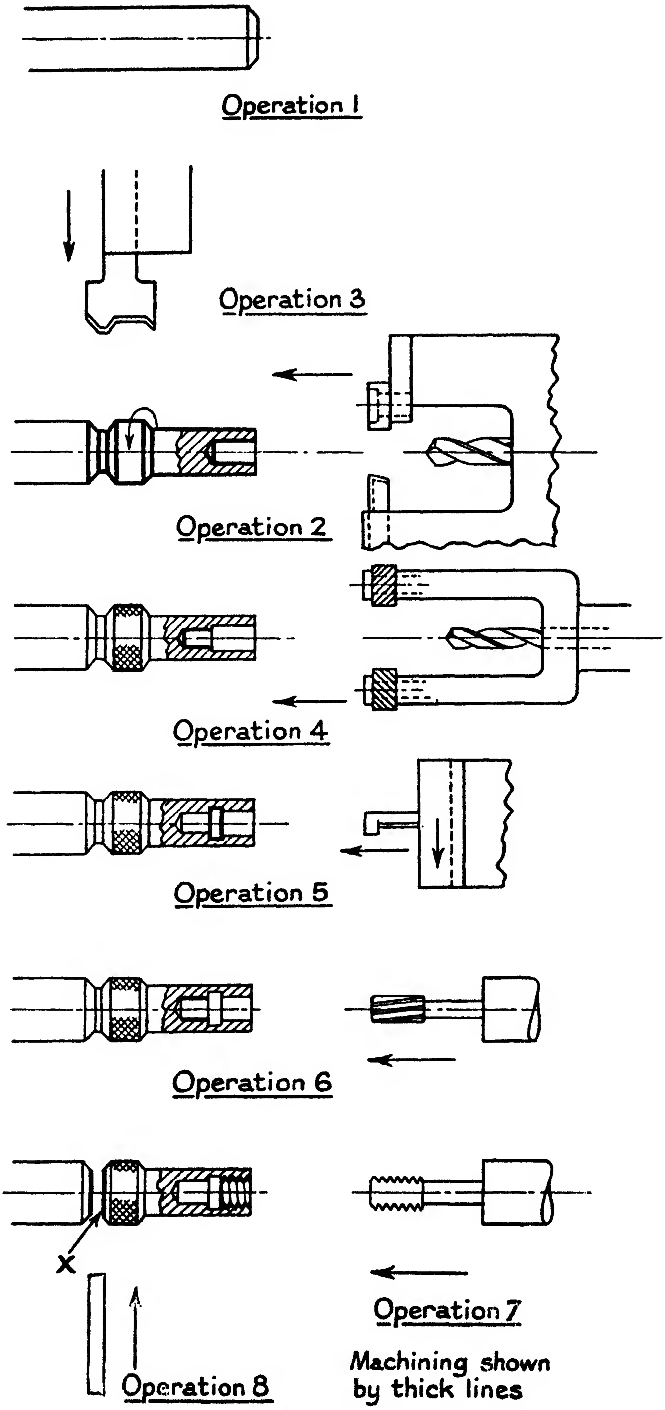


Fig. 8. Capstan Lathe Lay-out

The operations on a cast sleeve are shown in Fig. 9, which gives an idea of the method of handling a typical component. The successive stages are as follows—

Operation 1. Rough turn two outside diameters and two important inside diameters. Rough face end and flange. The bar carrying the cutters boring the hole is steadied by the bush in the lathe spindle. This is an important consideration with work having a through hole large enough to allow a boring bar to be used. The two operations proceed simultaneously.

Operation 2. Bore two unimportant inside diameters.

Operation 3. Second turn important outside and inside diameters. Note that the thickness of the flange is controlled by the initial adjustment of the tools and not from stops on the machine.

Operation 4. Finish turn important diameters. The smallest possible allowance of metal is left on for this operation so that the fine limits can be worked to for a reasonable time without tool wear.

This example illustrates clearly the cost of accuracy, it being necessary to turn the important surfaces three times in order to maintain the desired limits.

CENTRE LATHES. The simplest form of centre lathe is the engine lathe equipped with a set of tools to perform a particular operation. The work is centre-drilled at each end and carried on corresponding male centres, and it is driven by a chuck or clamp fastened to one end. Centre lathes are suitable for handling shafts and other comparatively long parts, especially those which have to be subsequently ground. The centres may be put in on a capstan lathe or a special centring machine.

It is possible to handle practically all external shapes on a centre lathe, but long tapers and forms and recessed shoulders should be avoided, as to form them may require a special operation.

One development of the centre lathe is the *multi-cut* lathe, and a diagram of a typical tool lay-out for this type of machine is shown in Fig. 10. It will be noticed that the front side moves into the work and then along, finishing up at the position shown dotted, whilst the rear slide feeds into the work. All the tools are cutting simultaneously and the work must be strong enough to withstand their action.

Thread Rolling. The forming of threads on small screws by rolling blanks between grooved dies has been standard practice for many years. Recent developments, particularly the

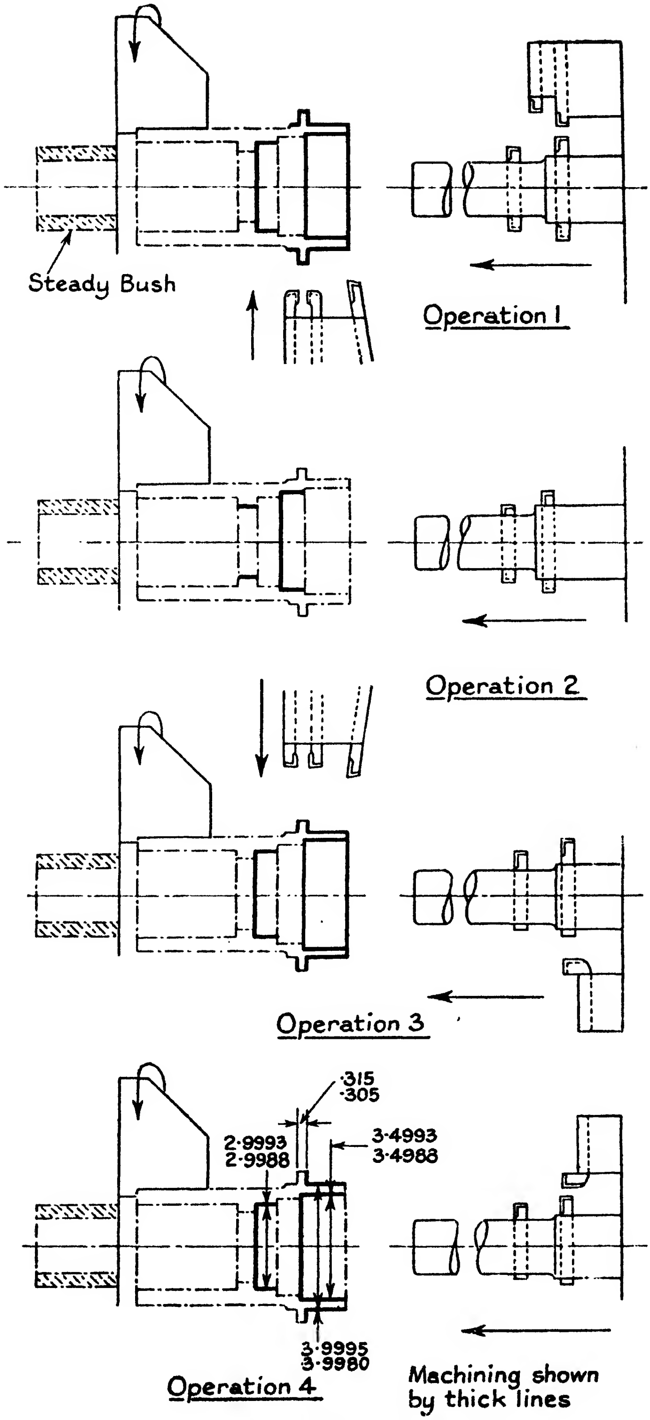


FIG. 9. TURRET LATHE LAY-OUT

centreless thread rolling machine, have enlarged the scope of thread rolling considerably and it is possible to roll threads as large as $1\frac{1}{4}$ in. diameter if they are short, whilst a $2\frac{1}{2}$ in. length $\frac{3}{4}$ in. diameter thread can be handled. The quality of the

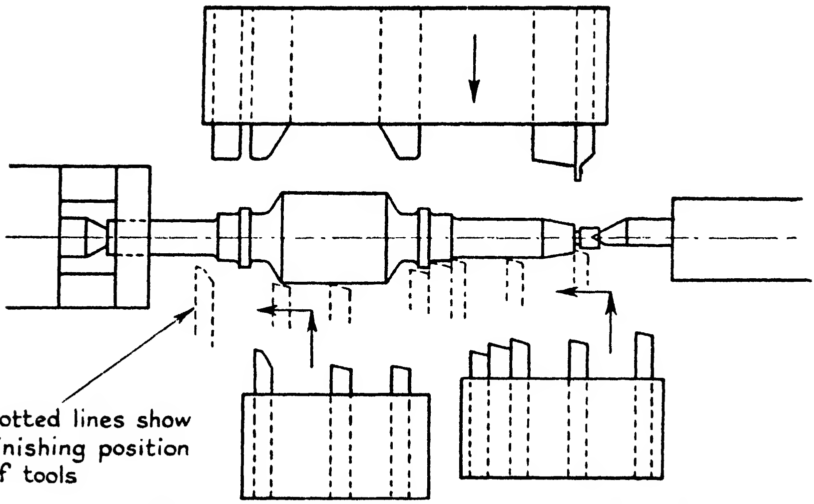


FIG. 10. MULTI-CUT LATHE TOOL LAY-OUT FOR WORM SHAFT

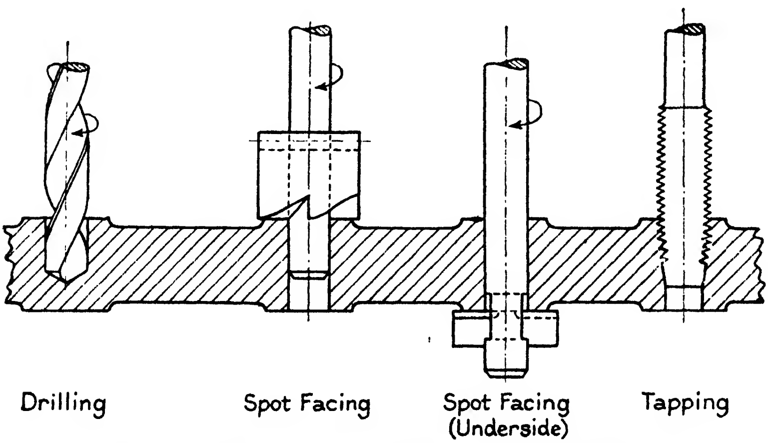


FIG. 11. TYPICAL DRILLING MACHINE OPERATIONS

threads is excellent; accuracy, finish and strength, particularly fatigue strength, being superior to cut threads. The output of about 30 threads per minute makes the method essentially one for quantity production. The design of parts can sometimes be simplified if it is remembered that no means of holding need be provided.

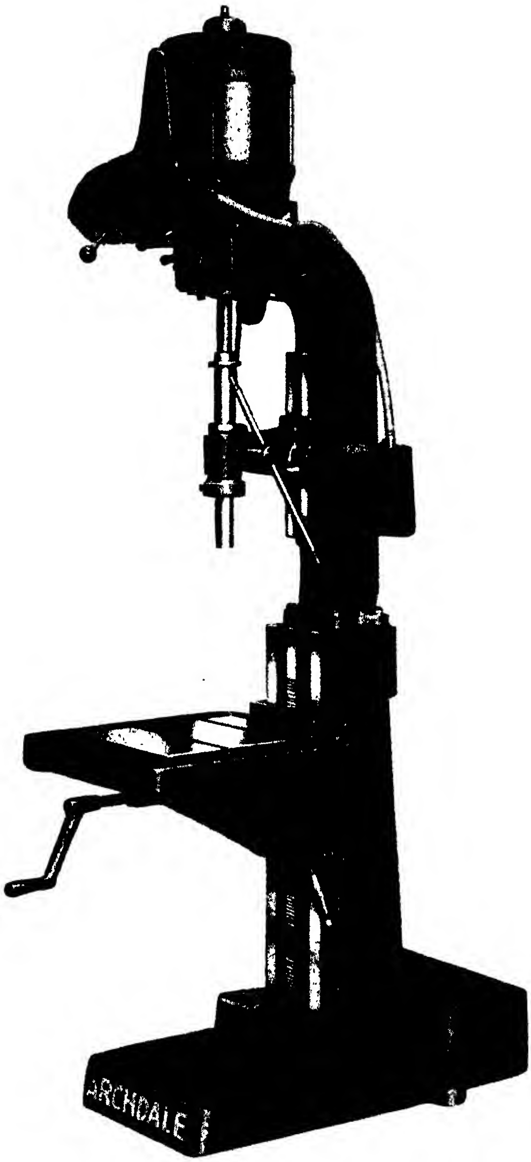


FIG. 12. ARCHDALE SENSITIVE DRILLING MACHINE
(Associated British Machine Tool Makers Ltd.)

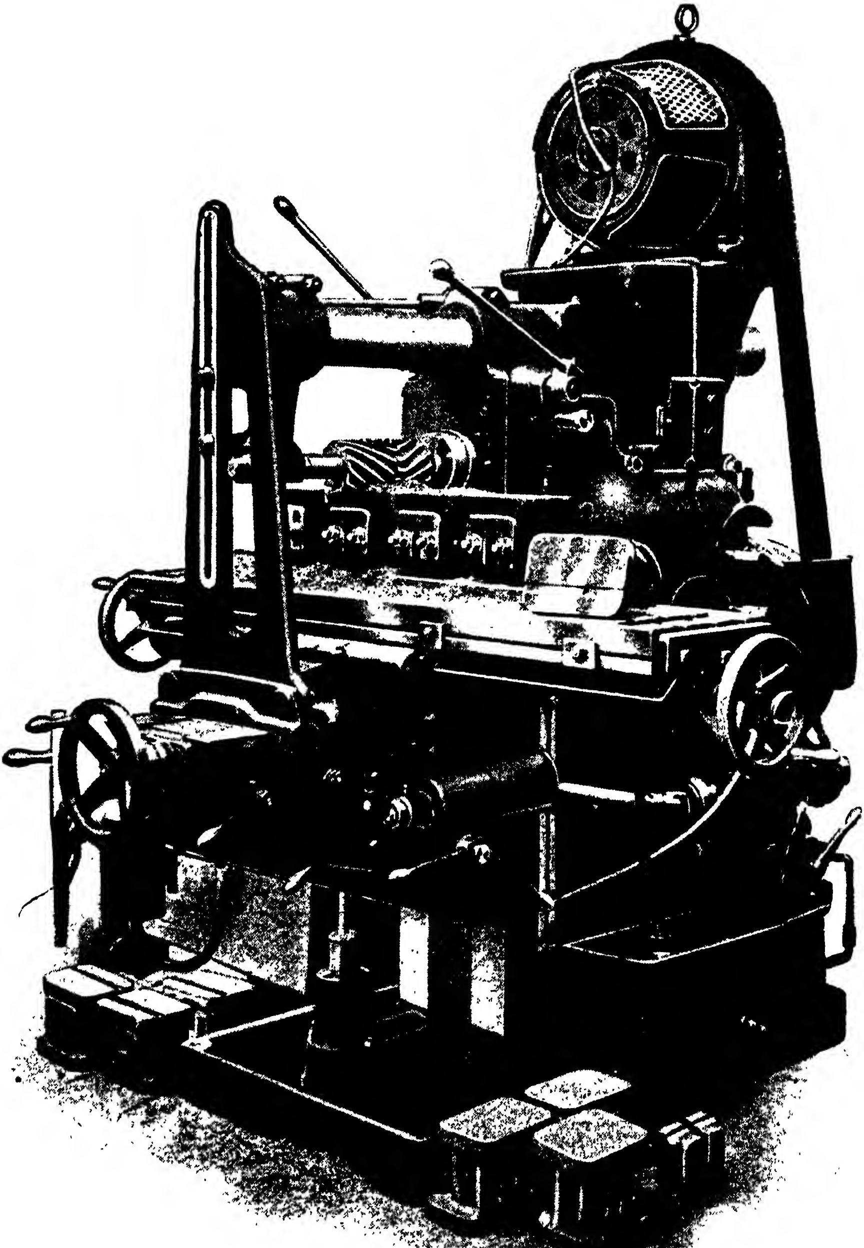


FIG. 13. PARKINSON HORIZONTAL MILLING MACHINE IN OPERATION
(Associated British Machine Tool Makers Ltd.)

Drilling. Whereas in the case of the lathe the work revolves and the tools do not, in the case of the drilling machine the work is stationary and the tools revolve. This feature limits the use of the drilling machine to the machining of holes, the finishing of holes by reaming, the tapping of threads, and the facing of the part immediately around the ends of a hole. Typical drilling machine operations are shown in Fig. 11.

Drilling machines are of several types. A sensitive drill, suitable for light work, is shown in Fig. 12. For large quantity production multi-drilling heads are used, by means of which a number of holes which are not too close together may all be drilled at the same time.

Milling. The milling process is used for machining a large variety of work. Revolving circular saw toothed cutters are used, past which the work is fed. An example of a horizontal milling machine is shown in Fig. 13, whilst special machines are available for milling keyways, worms and threads, cams and profiles, slotting screw heads, etc.

Some typical milling operations are shown in Fig. 14.

Flat surfaces may be milled by the two methods, both widely used, shown at *c* and *d*. The limitations in milling stepped surfaces in one operation should be noted, as it is sometimes possible to eliminate unnecessary work by allowing the cutter to run out as shown instead of calling for a square or straight edge.

The two methods of milling keyways and slots are shown at *a* and *b*. In the first case a saw-shaped cutter is used, and the bottom of the end of the slot is rounded as shown. This type of slot is the quickest to produce. In the second case an end-cutting tool is used and this forms a flat bottomed slot with rounded ends, which is used for fixed keys, but is comparatively expensive to produce as the cutting speed is limited by the fragility of the cutter.

A simple example of gang milling is shown at *b*, where two cutters are mounted (in a gang) on the same arbour for milling a tongue. By using several cutters of suitable size and shape a great variety of work can be performed by gang milling.

Form milling may be carried out by using suitably shaped cutters. At *e* is shown the method of milling a splined shaft. The shaft is rotated through 90° between each cut.

Broaching. Broaching is now used extensively for producing splined and other shaped holes and for finishing round holes to size. The broaching of a splined hole in a gear blank is shown

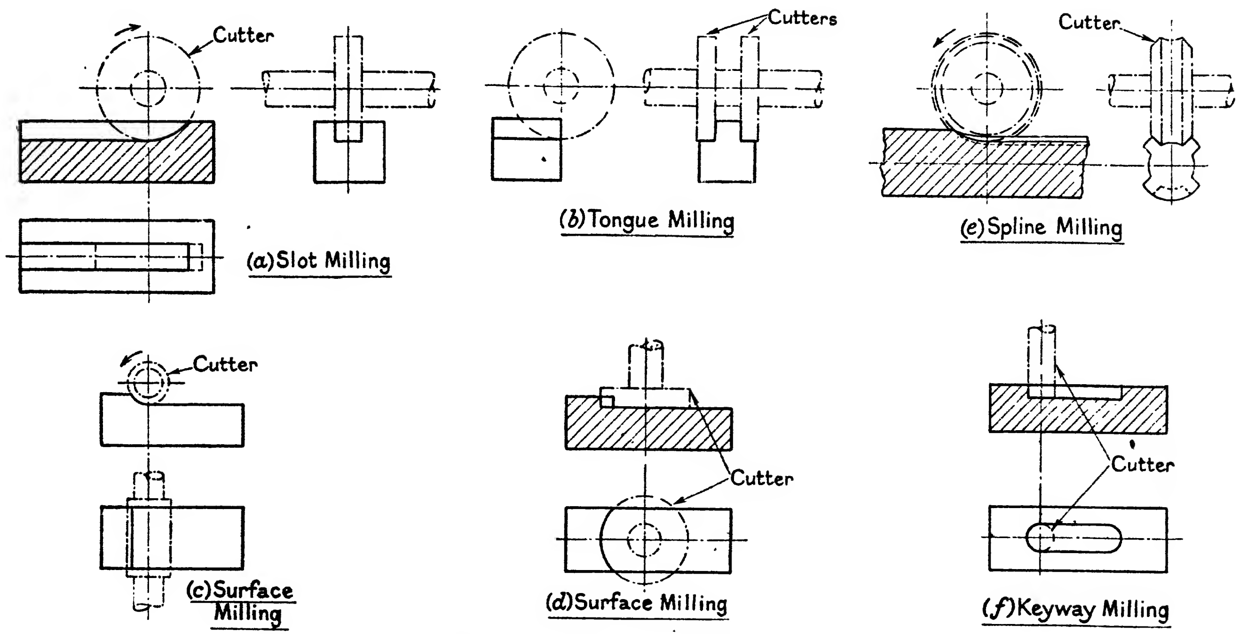


FIG. 14. MILLING OPERATIONS

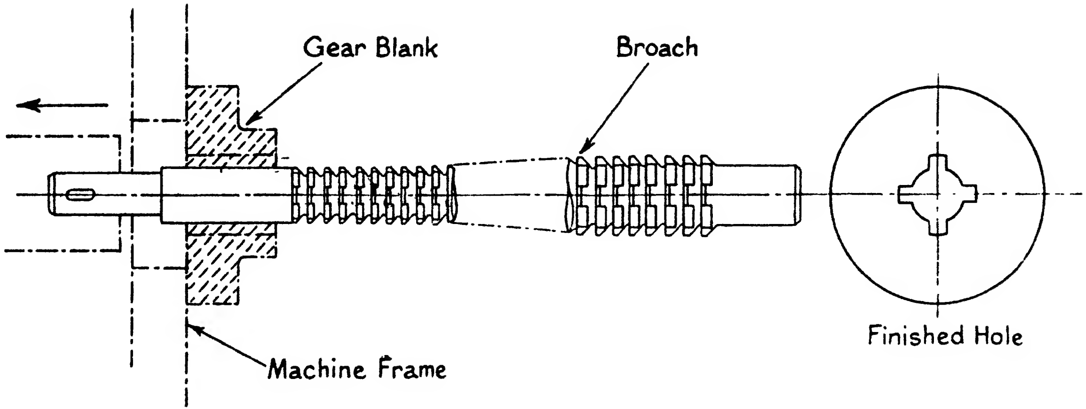


Fig. 15. Broaching Splined Hole

in Fig. 15. The broach is pulled through the hole, which has previously been drilled, by a ram which is either screw or hydraulically actuated. The pressure of the cut keeps the gear against the machine frame and no holding devices are required.

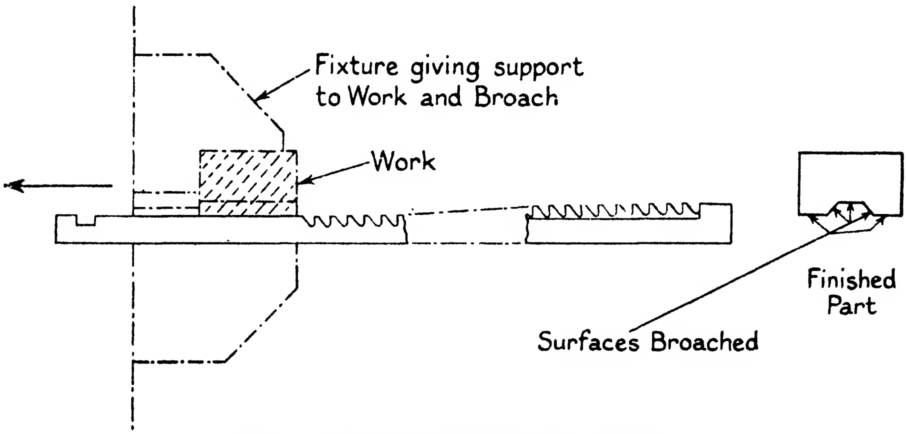


Fig. 16. Surface Broaching Operation

The broach consists of a series of teeth gradually increasing in size, the number of which, and therefore the length of the broach, depending on the amount of material to be removed

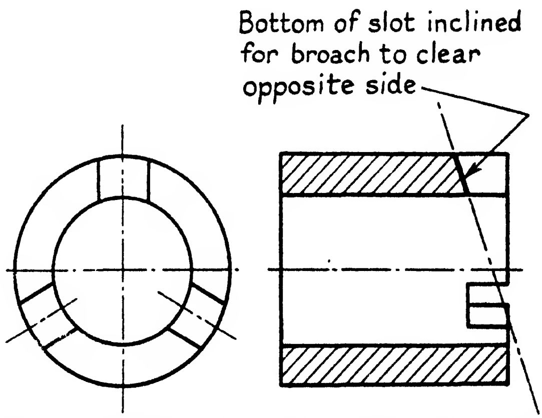


Fig. 17. Slotted Bush designed for Broaching

and the length of the part. The length of the broach shown would be about 5 ft. and the cut per tooth about 0·005 in. The cutting time would be about 20 sec.

Broaches of this type may be used on all holes where the shape is such that a sufficiently strong broach may be used,

and where the shape of the part is such that the passage of the broach is not interfered with.

Where quantities are sufficient to warrant the initial outlay, broaching may be used with advantage instead of milling.

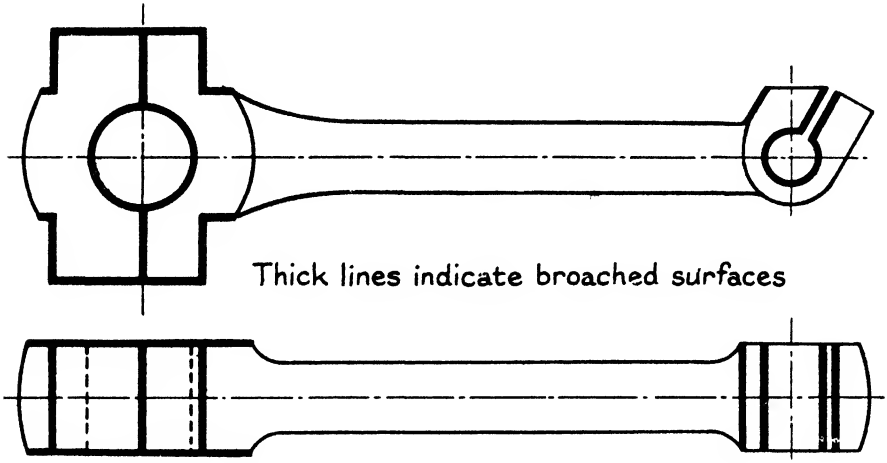


FIG. 18. CONNECTING ROD SHOWING SURFACES FINISHED BY BROACHING

The part, however, must be of suitable design and the amount of material to be removed must not be too great. The lay-out of a typical surface broaching operation is shown in Fig. 16. The broach and work must be adequately supported to ensure uniform results.

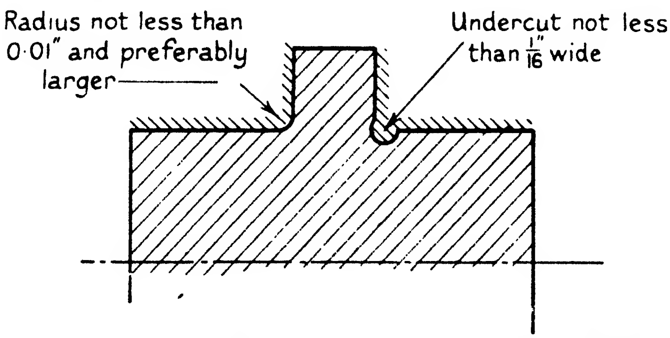


FIG. 19. ALTERNATIVE CORNERS FOR GROUND PARTS

Parts intended to be finished by broaching must be designed to allow the broach to be used without interference. The slotted bush in Fig. 17 shows how this may be done.

An example of the extent to which broaching may be used is shown in Fig. 18, which illustrates a connecting rod with many of the working surfaces (indicated by thick lines) finished by this method.

Grinding. Abrasive wheel grinding machines are widely used for finishing parts, especially hardened parts, accurately to size.

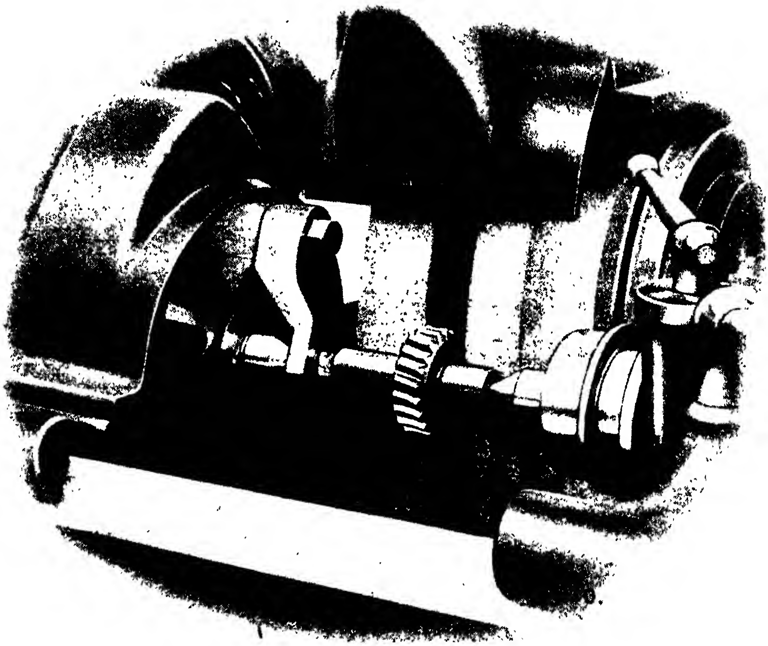


FIG. 20. CHURCHILL GRINDING MACHINE
Showing close-up of grinding operation using twin wheels
(*Associated British Machine Tool Makers Ltd.*)

Abrasive wheels are made with cutting materials of various degrees of coarseness. The coarser the wheel the quicker the material will be removed, but the surface finish will be poorer. Wheels must be selected, not only to suit the particular material being ground, but also the finish which it is desired to produce.

Grinding is indispensable for finishing hardened parts accurately to size. A tolerance of 0·0005 in. may be maintained without difficulty.

The slight roughness left by grinding is not usually objectionable on hardened parts, although for high class bearing surfaces

grinding is usually followed by lapping. If the bearing surfaces of soft parts are ground, a much more durable surface is given by subsequent burnishing.

As it is practically impossible to grind a sharp corner, parts should always be designed with a definite radius in the angle between two adjacent ground surfaces, as shown in Fig. 19; or if this is impracticable, the corner should be undercut previous to grinding as shown on the right-hand of the figure.

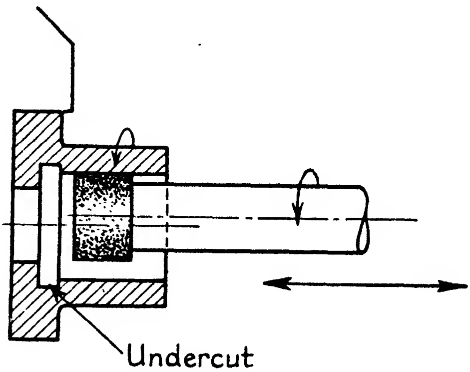


FIG. 21. INTERNAL GRINDING

The following are the chief production grinding processes.

1. EXTERNAL CYLINDRICAL GRINDING. This process is intended to deal with shafts, which are usually revolved between centres as shown in Fig. 20. Hollow work may be ground on a centred mandrel or held in a suitable chuck or fixture. It is possible with this type of machine to grind parallel diameters and shoulders, as shown in the figure; and also long and short tapers by setting over the work table at an angle with the grinding wheel.

2. INTERNAL CYLINDRICAL GRINDING. Machines for this purpose are designed to grind all types of round holes, the work usually being held in a chuck or fixture, and the wheel traversed backwards and forwards as shown in Fig. 21. Owing to the comparatively small size of the grinding wheel and its spindle, internal grinding is a rather delicate operation. For blind holes a reasonably long undercut should be allowed, and the wheel should not be used for facing shoulders if this can be avoided. The maximum lengths of hole which can be economically ground may be taken as follows—

Diameter of Hole	Maximum Length
(in.)	(in.)
¼	1
½	2½
1	5½
Over 1	Any reasonable length

3. SURFACE GRINDING. Surface grinding machines are used for grinding previously milled parts, and for grinding flat the ends of discs, rings, and other simple parts. For special parts the horizontal type of machine is used, its scope being similar to that of a milling machine. For flat parts, the vertical type, equipped with a magnetic chuck, can deal with a large variety of work without special appliances.

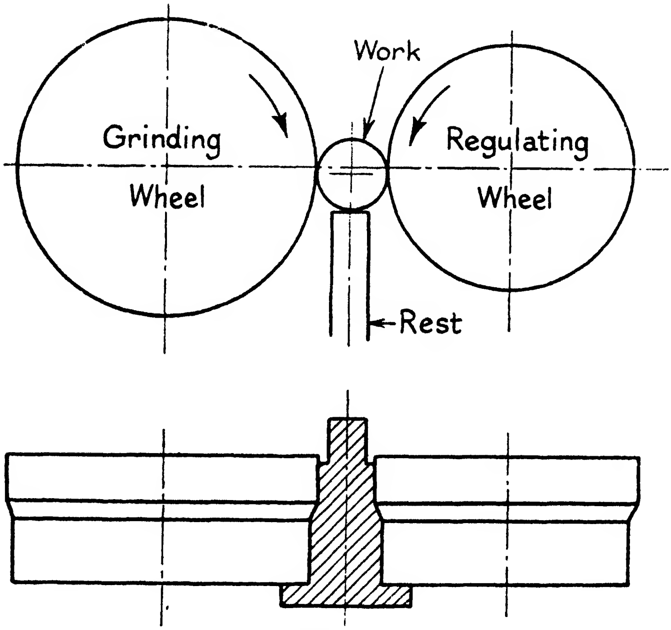


FIG. 22. PRINCIPLE OF CENTRELESS GRINDING WITH FORMED WHEELS

4. CENTRELESS GRINDING. The principle of the centreless grinding machine is illustrated in Fig. 22. The work is revolved between two grinding wheels, one rotating slowly, known as the *regulating wheel*, and the other, the *grinding wheel*, rotating at the usual grinding speed. The work is driven by the regulating wheel and supported by a rest as shown.

Two methods of operation are employed, the *through* method, which is suitable for plain parts such as simple pins, and the *plunge* method which is used for parts where through grinding would be impracticable. By the plunge method, tapers, forms, or several different diameters may be finished at one operation by means of suitably formed wheels as shown in the figure.

The fact that no centres or other means of holding is required

makes it possible to grind many components by this method which could otherwise only be ground with difficulty.

Lapping. For production work lapping is usually only applied to hardened bearing surfaces which are required to be as smooth as possible. Lapping should always follow an accurate grinding

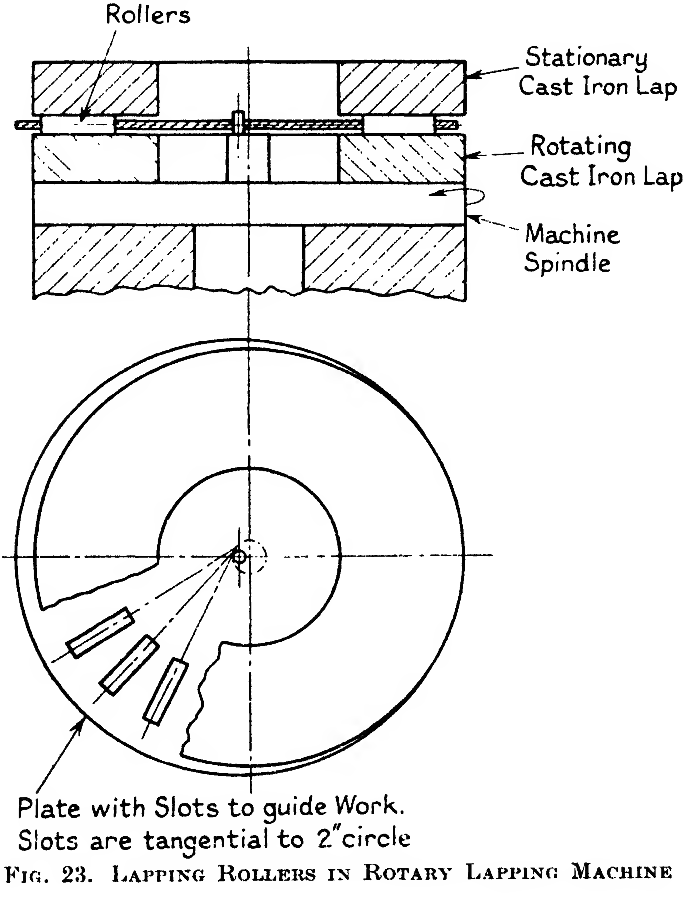


FIG. 23. LAPPING ROLLERS IN ROTARY LAPPING MACHINE

operation, and although a high degree of accuracy can be obtained, its outstanding advantage is the excellent wearing qualities of the lapped surface.

It is usually only necessary to lap male parts, and this is done between two flat cast-iron plates charged with a suitable abrasive, as shown in Fig. 23. It is, however, difficult to deal with any but fairly simple parts by this method.

Honing. While not the same in principle as the lapping process, honing is used as its equivalent for the finishing of

holes in cast-iron and hardened steel parts. The hones consist of strips of a fine abrasive held in a suitable holder with arrangements for adjusting to the required diameter. The hone is rotated and reciprocated in the hole and can be relied on to correct slight out-of-roundness and errors of parallellism. The normal allowance of material to be removed by honing is about 0·001 in. to 0·0015 in., and this may be reduced with advantage if the previous process is sufficiently accurate.

Diamond Boring. The diamond boring process has been

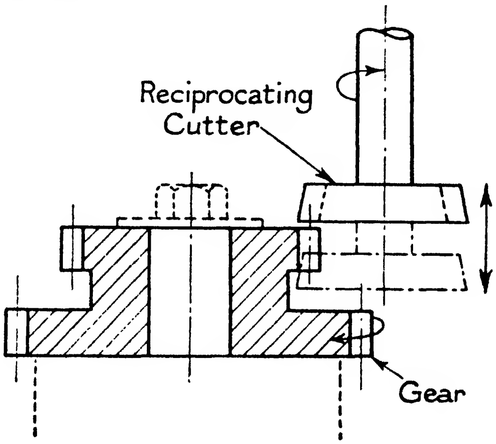


FIG. 24. PRINCIPLE OF SHAPING TEETH OF CLUSTER GEAR

developed as a means of finishing holes in non-ferrous metal parts with a similar accuracy to that obtained by honing. Diamond boring machines usually have a specially designed spindle or series of spindles running at a speed of 3 000 to 4 000 r.p.m. This process is essentially a finishing one and the diamond is only called upon to remove a small amount of metal. The feeds used are in the neighbourhood of 0·001 in. per revolution, or less, giving a mirror finish to the work.

Gear Cutting. There are two types of machines used for cutting straight and helical spur gears with involute teeth.

GEAR SHAPING MACHINES use a toothed cutter which meshes and revolves slowly with the gear which is being cut, whilst being reciprocated in a similar manner to a shaping machine. With these machines it is possible to cut both internal and plain gears and also cluster gears: the principle of operation is shown in Fig. 24.

GEAR HOBBING MACHINES use a worm-shaped cutter or hob which revolves continuously in mesh with the work. When

cutting spur gears it is traversed across the face of the gear as cutting proceeds; but the process is not suitable for cluster gears. Fig. 25 illustrates the hobbing of a spur gear.

The hobbing process is almost invariably used for very fine gears and for worm wheels. Splines, when suitably designed, may also be cut by this process.

Bevel Gears are invariably cut by a shaping process and care must be taken to allow space for the cutters to work.

Gear Finishing. Hardened gears require some process to

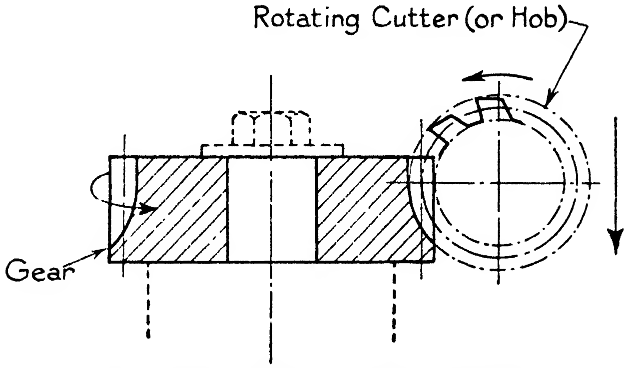


Fig. 25. Principle of Gear Hobbing

remove variations introduced by the hardening process. For straight spur gears grinding may be used if care is taken in the design that the grinding wheels employed may pass the whole length of the tooth. When it is impossible to use a grinding machine, as in the case of cluster and helical gears, the lapping process may be used, which is carried out by rotating the gear with a gear-shaped lap and at the same time reciprocating it. This process is suitable for finishing any spur or helical gears.

Small Tools. Cutting tools, abrasive wheels and miscellaneous standard equipment for use with machine tools are available in such variety that it is impossible to deal with them here. They may be found, described in detail, in manufacturers' and dealers' catalogues. The question as to whether parts should be designed to use as much standard equipment as possible must depend on the quantities it is intended to manufacture. For small quantities, standard equipment should always be used as far as possible.

Jigs and Fixtures. It is often found necessary to provide a jig or fixture for use when performing drilling, milling, or other

machining operations. The part to be machined is located from some convenient point or points and is often clamped in position to prevent movement. In the case of a jig means are also provided for guiding the cutting tool.

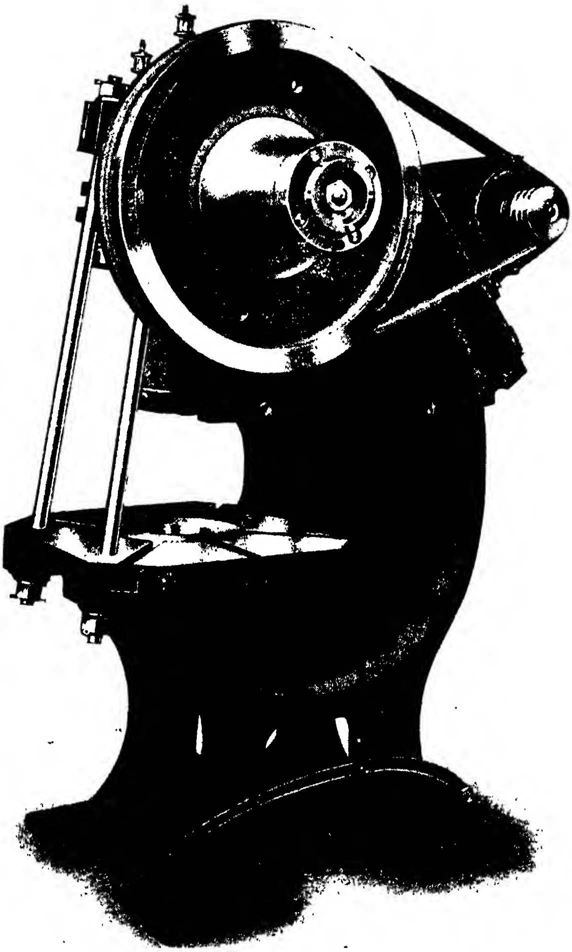


FIG. 26. TAYLOR & CHALLEN NO. 370 PRESS
(Taylor & Challen Ltd.)

In designing a part which is likely to be machined in a jig or fixture, care should be taken that well-defined locating points, surfaces, or holes are provided and that the part can be held without difficulty. It is sometimes advisable to

provide holding or locating points which are subsequently removed.

PRESS WORK

The use of specially designed tools for the manufacture of sheet metal articles is an important branch of quantity production. The tools are used in conjunction with presses of various designs, a typical example of which is shown in Fig. 26. The ram of the press, to which one part of the tool is attached, runs in vertical guides and is reciprocated by a crank and connecting rod. The machine is arranged so that on depressing the clutch pedal the crankshaft makes one revolution and stops with the ram at the top of the stroke. The time of each operation is the time of one revolution of the crank plus the time for inserting and withdrawing the articles. By the use of automatic feeds, the crankshaft may be run continuously and the time reduced accordingly. For instance, the speed of the press illustrated would be about 100 strokes per minute, and a simple article completed in one operation could be made at the rate of one per stroke. This, of course, applies only to a comparatively simple article; but even if it is necessary to carry out a series of press work operations it is usually found that articles designed to be made in this way can be produced more cheaply than if made by other means, provided that there are sufficient quantities to offset the cost of the special tools.

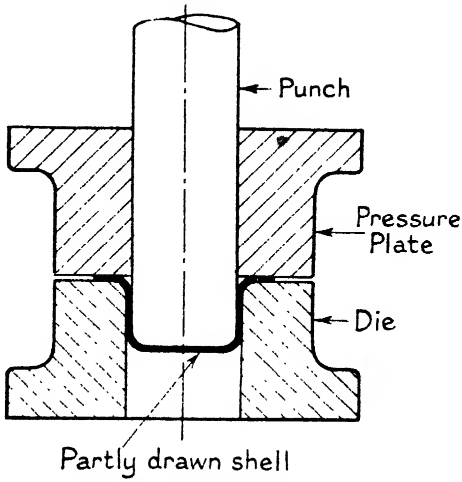


FIG. 27. DRAWING TOOL
Used in double action press

Presses. These may be divided into four main types—

1. SINGLE ACTION CRANK PRESSES; made in many sizes to accommodate work from the smallest article to panels, frames, etc.

2. DOUBLE ACTION CRANK PRESSES; used for drawn articles. These have two rams, one carrying the punch and the other the pressure plate (see Fig. 27). The pressure plate

descends first and holds the blank whilst the drawing takes place.

3. COINING PRESSES. These are of massive construction and are used, as their name implies, for embossing coins and similar articles. The pressure is applied by a toggle which gives a slow squeezing action very suitable for this type of work.

4. SCREW PRESSES. The ram is actuated by a screw, which is operated by power or hand. These presses are used where, owing to variations in the thickness of material, the positive action of a crank press would be undesirable. Hand screw presses are also used for small miscellaneous press work.

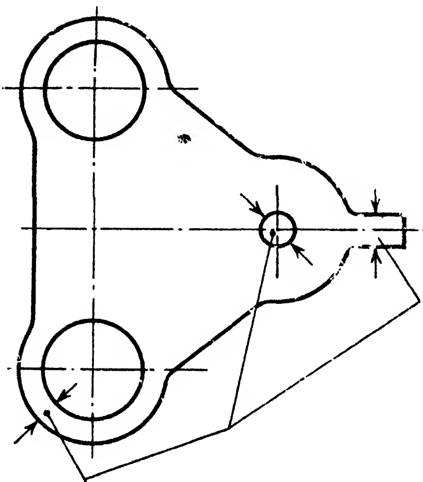


FIG. 28. SHEET METAL BLANK
Showing proportons

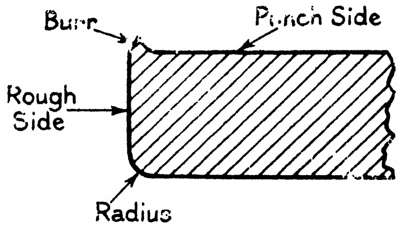


FIG. 29. ENLARGED VIEW OF THE EDGE OF A PRESSING

A pressing is normally produced by a series of simple operations, the more important of which are given below. Where quantities are large it is possible to design special tools to combine several operations.

Blanking and Piercing. The operation of shearing from the sheet or strip metal, the flat blank from which an article is to be made, is known as *blanking,* and that of shearing holes out of the blank is known as *piercing.*

A typical pierced blank is shown in Fig. 28. It is difficult to produce blanks which have any part with a width less than the thickness of the material; and preferably twice the thickness of material should be allowed. Holes may be pierced down to a diameter equal to the thickness of the metal; but when smaller than this they should be drilled.

Although thin metal may be sheared with clean edges, material over $\frac{1}{32}$ in. thick leaves an edge as shown in Fig. 29.

The thicker the metal the more pronounced is the radius and the burr. The edge may be somewhat improved by forcing through a die slightly smaller than the blanking die, but of course this adds to the expense. It is preferable to indicate on

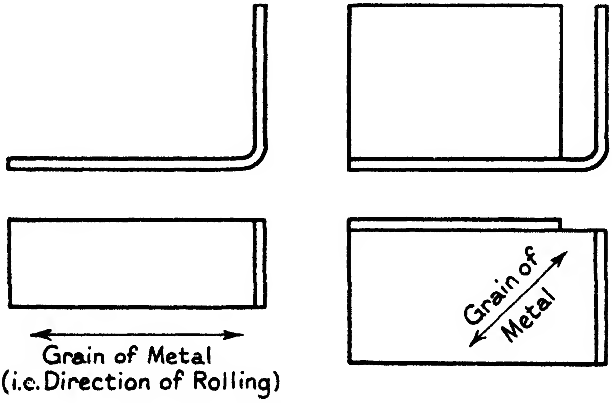


FIG. 30. BENDING OPERATIONS

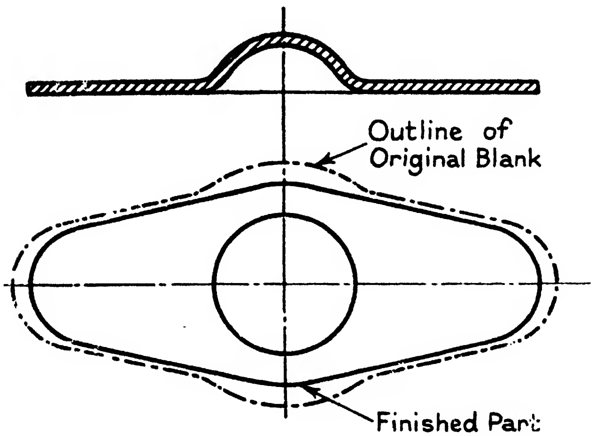


FIG. 31. RAISING OPERATION

the drawing on which side of the article the burr is preferred, or if it must be removed. If the ordinary blanked edge is not good enough, this also should be indicated.

Bending. Bends of all shapes are easily made in sheet metal, although with hard rolled material it may be necessary to arrange the grain of the metal as shown in Fig. 30 to prevent cracking.

Raising. This operation is rather more severe than a simple

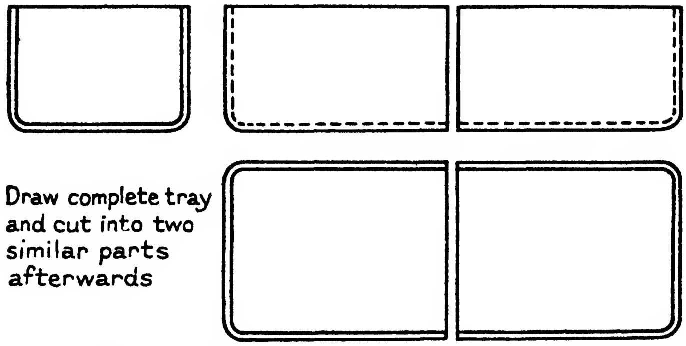


FIG. 32. MAKING TWO PARTS AT A TIME BY DRAWING PROCESS

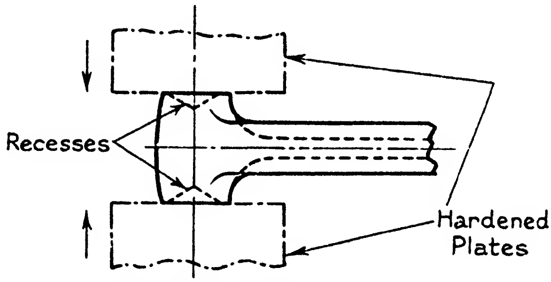


FIG. 33. FLATTENING BOSSES BY COINING PROCESS

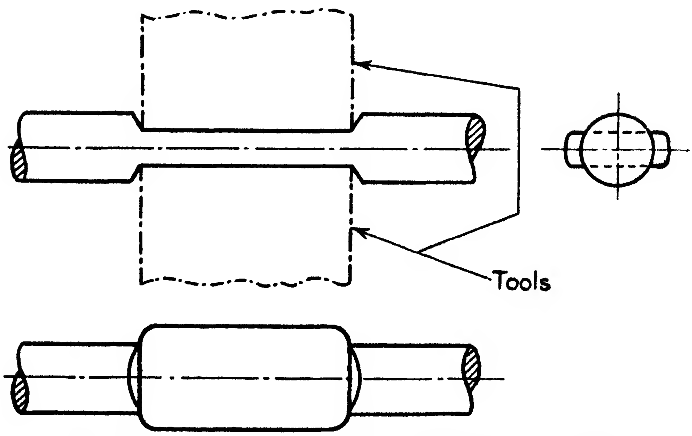


FIG. 34. WIRE FLATTENED BY COINING PROCESS

bending one, as the metal has actually to be pulled and stretched from the surrounding parts. A simple raised part is shown in Fig. 31, which also shows the original blank, the shape of which is derived by experiment.

Drawing. The production of shells and other comparatively deep articles from sheet is done by the drawing process. A typical drawing tool is shown in Fig. 27. In order to obtain a shell with a uniform wall thickness and free from wrinkles, it is necessary to apply a considerable load to the pressure plate,

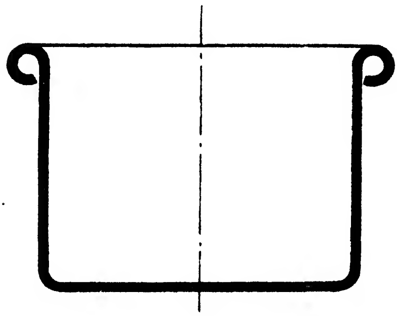


FIG. 35. BEADED EDGE

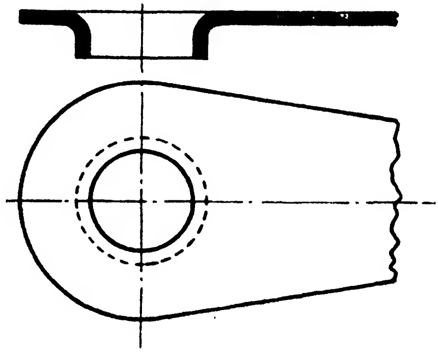


FIG. 36. PLUNGED HOLE

and drawn parts should be so designed that the use of a pressure plate is possible. For example, the pressed tray shown in Fig. 32 would be drawn complete with a second similar tray and subsequently split into two.

Coining. In addition to the production of coins and similar embossed articles, the coining press may be used for flattening forgings and similar parts by squeezing between hardened flat plates. The area to be flattened should be kept to a minimum in order to reduce the pressure required. This is effected in the example shown in Fig. 33 by recessing each face. The flattening of wire may also be carried out by coining as shown in Fig. 34.

Beading and Wiring. The edges of sheet metal parts may be stiffened and the parts made to appear more substantial by turning over the edge as shown in Fig. 35. This is easily accomplished by simple tools in the case of parts with an even edge. For large parts the operation is often carried out by rolling, the edge being formed round a wire core which is left in position.

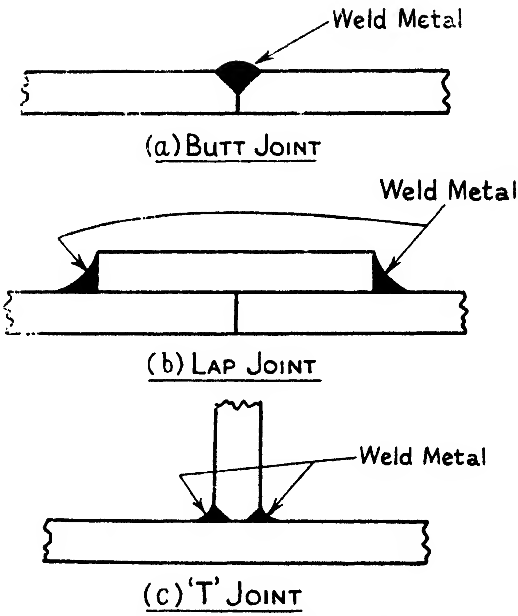


Fig. 37. Fusion Welds

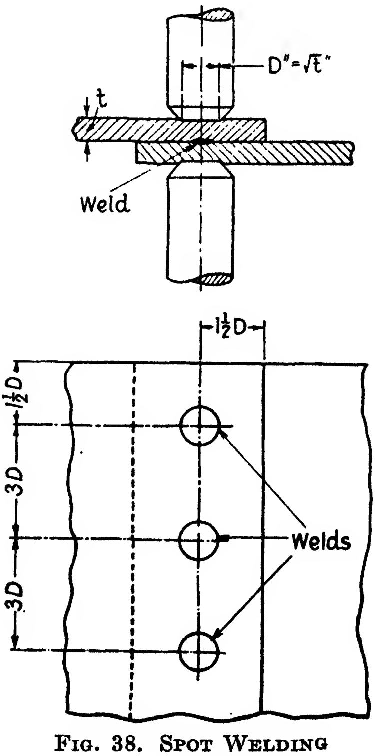


Fig. 38. Spot Welding

Plunging. A typical plunged hole is shown in Fig. 36. The blank which must be of fairly soft material, is pierced with a small hole and then punched as shown.

JOINTING

Welding. The use of welding as a means of jointing is rapidly extending. The processes generally used for production work are as follows—

FUSION WELDING. This is the process of joining metal parts by heating them locally to melting-point and usually adding additional metal from a suitable rod. The source of heat is either an oxygen-gas flame or an electric arc.

Fusion welding is used especially for large work where parts may be built up from steel plates, so dispensing with castings. For light work the use of fusion welding is limited, owing to its expense, to parts which cannot conveniently be made otherwise. In Fig. 37 are illustrated some typical fusion welds. When using metal less than $\frac{1}{8}$ in. thick the bevelling of the edges of the plate may be omitted. Steel may be welded with ease, but other materials require a certain amount of care.

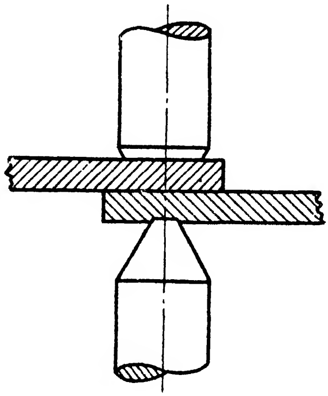


FIG. 39. FLAT ELECTRODE FOR INVISIBLE SPOT WELD

ELECTRIC SPOT WELDING. This is the most important welding process for light production work, and it has largely superseded riveting or soldering.

A spot welding machine has two arms, each of which carries an electrode, between which the two parts are placed, as shown in Fig. 38, and a pedal is pressed which closes the electrodes together and switches on the current for a predetermined time. The resistance of the material between the electrodes causes sufficient heat to be generated to fuse the two parts together. The process takes only a few seconds and the rate of output is usually limited by the time taken to handle the parts.

It will be noticed that a small depression is left by the electrodes, but where this is objectionable it may be eliminated on one side of the work by making one electrode flat, as shown in Fig. 39. For making pressure-tight

seams special machines with revolving disc electrodes are used.

Mild steel is the material most suitable for spot welding, but it should be clean and free from rust and scale.*

ELECTRIC BUTT WELDING. For this process the work is held in heavy copper clamps, which act as electrodes. One of the clamps is usually mounted on a slide so that pressure may be applied during the welding operation.

The simplest application is shown in Fig. 40 (*a*). Similar or dissimilar metals may be welded and the rods need not be of

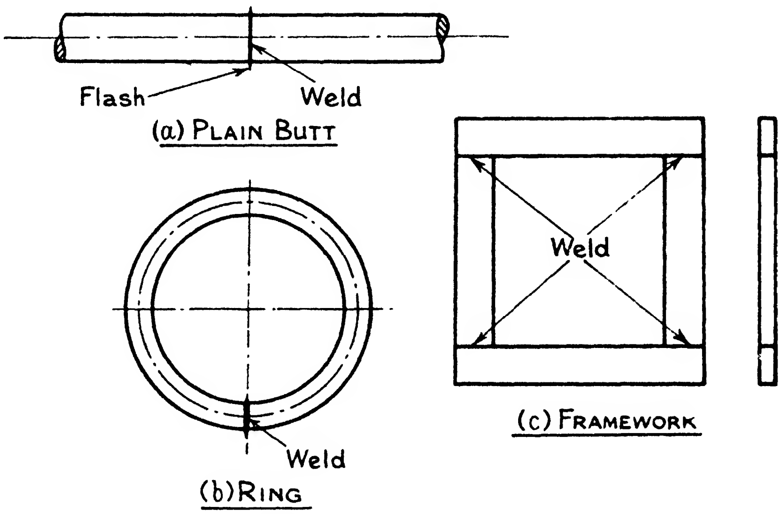


FIG. 40. ELECTRICAL RESISTANCE WELDED BUTT JOINTS

the same size. A small flash is thrown up by the weld but this may be removed easily. Rings and frames as shown at Fig. 40 (*b*) and (*c*) may be butt welded without difficulty.

Typical examples of parts assembled by the various electric resistance welding processes are shown in Fig. 41.

Soldering. There are a number of soldering processes in use to-day, of which the best known are the following.

SOFT SOLDERING. The process of joining metal parts by low melting point solders containing between 50 and 70 per cent lead, the remainder being tin, is extensively used for light work where great mechanical strength is not required. The solder

* For further information on Welding references should be made to the publications of the Advisory Service on Welding.

is applied by means of a soldering iron, or the parts may be heated by means of a blowpipe and the solder applied in rod form. *Sweating* is carried out by coating the two surfaces to be joined with a thin coating of solder (known as *tinning*) and heating them with a blowpipe after they have been placed in position, so causing the two layers of solder to fuse together.

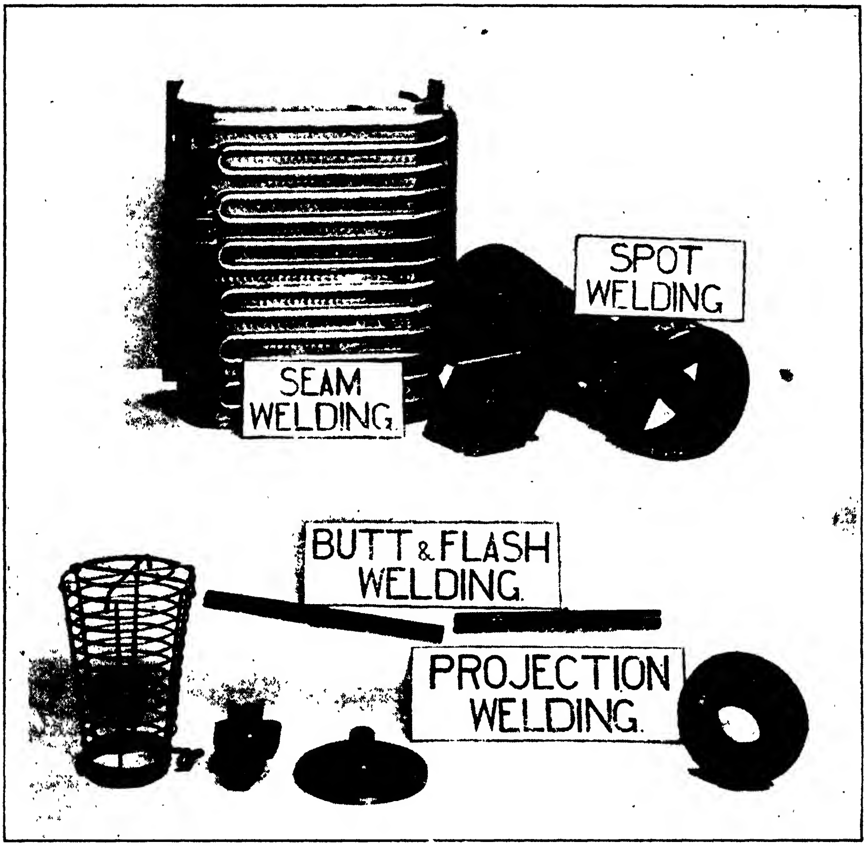


Fig. 41

Brazing. This may be described as a high temperature soldering process, using a copper alloy with a comparatively low melting point as the jointing medium. Ordinary brazing metal requires a dull red heat to melt it and this may cause undesirable softening of the parts and an objectionable scale. By using a special furnace with a reducing atmosphere scaling can be eliminated and exceptionally sound joints

obtained. Brazing alloys containing silver have a lower melting point than the ordinary type and are to be preferred where softening of the parts is feared. These "silver solders" give a white joint and cause little scaling.

HARD OR SILVER SOLDERING. This is a similar process to brazing but the solder contains a considerable percentage of silver. This has the effect of lowering the melting point slightly and giving a white coloured joint, which is particularly desirable with nickel alloys such as nickel silver and Monel.

SOLDERING ALUMINIUM. The soldering processes just described are unsuitable for use with aluminium, and for hard soldering this metal an aluminium alloy containing about 12 per cent of silicon may be used. This can be obtained in the form of tube containing a suitable flux. Soft soldering is carried out with a special chemical mixture* which is spread on the surfaces to be joined and heated with a blowpipe. This forms a joint of pure zinc which alloys perfectly with the aluminium and gives very satisfactory results.

FINISHING PROCESSES

It is usual to treat exposed and visible parts with some finishing process to prevent corrosion, give a decorative appearance, or both. The choice of a decorative finish is largely a matter of fashion and personal taste, and although cost must also be taken into account; it must be borne in mind that it is as important for a machine to be pleasing to the eye as it is that it should function properly.

Finishing usually entails the preparation of the surface of the material by mechanical or chemical means, followed by the application of the protective coating.

Preparatory Processes. SAND AND SHOT BLASTING give a matt finish. Their abrasive action is useful for removing scale from hardened parts. The surface forms an excellent key for enamels.

BARRELLING. Small articles may be freed from burrs and polished by tumbling in a rotating barrel with such substances as sand, flints, acid, sawdust, leather, and hard steel balls. By using a suitable medium, small pressings may be finished in this way without touching by hand.

POLISHING is usually performed by hand with a rapidly rotating fabric mop. The process is expensive but gives results

* "Flinso" supplied by Grant & West Ltd., 17 South Street, London, E.C.2

it is impossible to obtain otherwise, and is generally used where a first-class polish is desired.

Protective Coatings. Brass Plating, used chiefly for plating steel to give a gilt or brass appearance.

Cadmium Plating, used extensively as a non-decorative rust-protective finish for steel parts.

Chromium Plating. The standard decorative finish usually applied on a polished surface, which may have a preliminary deposit of nickel. Chromium is untarnishable and has a beautiful lustre.

Nickel Plating. A decorative finish used where chromium is too expensive. Nickel tends to tarnish in ordinary atmospheres.

Copper, Tin, and Zinc Plating. These are used only for special purposes. Zinc is usually deposited by the galvanizing process.

Enamels and Lacquers. Large surfaces are most conveniently protected by applying an enamel or lacquer by spraying, brushing or dipping. There are several varieties of these and they may be obtained in many colours. Provided the surface of the metal is properly prepared and the finish applied correctly, they are quite reliable. For high class work it may be necessary to apply several coats of lacquer, rubbing down with an abrasive between each coat.

The most common types of enamels and lacquers are as follows—

Vitreous or Porcelain Enamel, a hard-wearing enamel resembling porcelain. It is used chiefly for hardware and can only be applied to iron and steel owing to the high temperature necessary to cause vitrefaction.

Stoving Enamels. Where parts can be stoved, these enamels are the most satisfactory. It is necessary to choose an enamel which does not require a temperature higher than the article will stand without damage.

Lacquer. Cellulose lacquers are in general use and are easily applied by spraying or dipping. They dry quickly and wear well and are especially suitable for parts which cannot be stoved.

Rustproofing. There are several rustproofing processes for steel among which are the following. All of these leave a rough finish not suitable for wearing surfaces.

Coslettizing. A chemical finish giving a black surface, particularly suitable as a foundation for enamel.

SHERARDIZING. A patented process whereby metallic zinc is deposited on the parts.

OIL FINISH. The parts are heated to a dull red heat and quenched in linseed oil, the excess oil being then burned off.

Japanning. This process is suitable for small parts such as springs. The parts are coated by barrelling them with a small quantity of liquid japan and then stoving at about 300° F.

Aluminium Anodizing. This is an electrical process confined to the treatment of aluminium and its alloys. The article is given an adherent coat of aluminium oxide which has an attractive lustre and which strongly resists further corrosion. Dyes may be used to give various colours and a coating of beeswax improves the weather-resisting properties.

Brass Finishes. As brass is normally resistant to corrosion, finishes are usually confined to improving its appearance. Besides those already mentioned, brass is also finished in the following ways—

1. Polished and coated with clear lacquer to prevent tarnishing.
2. Dipped in dilute acid and lacquered.
3. Treated chemically to give a blue-black "bronze" finish and lacquered. The surface is usually polished before bronzing.

CHAPTER V

INTERCHANGEABLE MANUFACTURE

THE production of a machine involves two separate sets of processes, the machining and forming to shape of the various finished component parts, and their assembly together to form the complete machine. By making all similar parts interchangeable, so that any two mating parts will assemble together, the costs of assembly are greatly reduced, and spare parts, which can readily be fitted by the user, can be supplied to replace worn or broken ones. It is not always possible or economical to have strict interchangeability, and in such cases a modified system such as selective assembly must be used.

The Limit System. In practice it is found impossible to manufacture parts to an exact size, as not only must unavoidable variations in the manufacturing processes be allowed for, but the inaccuracies of the measuring instruments must also be taken into account.

If measurement be made by means of a rule, an accuracy of, say, 0·020 in. may be guaranteed; i.e. the actual dimension, as measured by a more accurate measuring instrument, may be within 0·020 in. of the observed. Using light waves as the measuring standard, length may be measured correctly to within approximately one millionth of an inch.

The first obstacle, that of an inability to produce parts to an exact size, is overcome by stating that the size of the part shall lie between two dimensions termed the *limiting* dimensions. In Fig. 42 is shown diagrammatically a shaft fitting in a hole, and the effect of allowing a limit on the dimensions of each. The difference between the two limits is termed the *tolerance*; e.g. if the high limit on the shaft is 1·005 in. and the low limit 0·995 in., the tolerance $= 1{\cdot}005 - 0{\cdot}995 = 0{\cdot}010$ in. Similarly, the tolerance on the hole is $1{\cdot}020 - 1{\cdot}010 = 0{\cdot}010$ in. The maximum clearance is $1{\cdot}020 - 0{\cdot}995 = 0{\cdot}025$ in. and the minimum $1{\cdot}010 - 1{\cdot}005 = 0{\cdot}005$ in.

It is important to note, however, that in practice it is very unlikely that the extremes of fit will occur, also that in certain processes, particularly grinding, there is a tendency to work to the maximum metal condition. Calculations should be based on the average condition, in the example a clearance of ·015 in.

Fig. 43 illustrates the case where the shaft is larger than the hole and the parts are fitted together by force, or by heating the outer or cooling the inner element. The maximum and minimum amounts of interference are found in a similar way to the method described for clearances.

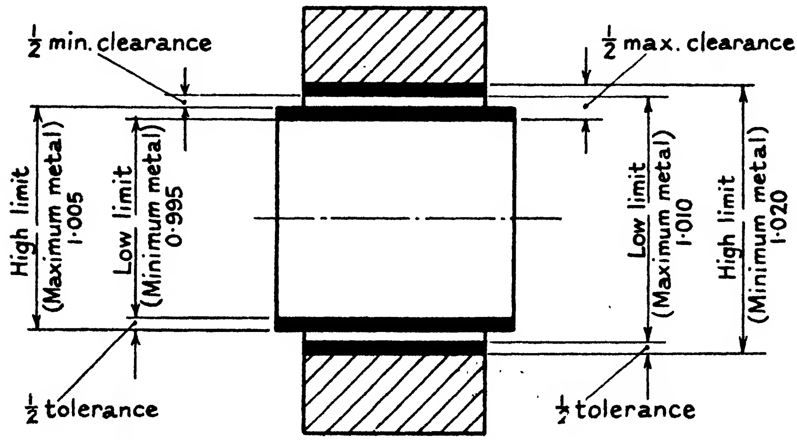


FIG. 42. CLEARANCE FIT

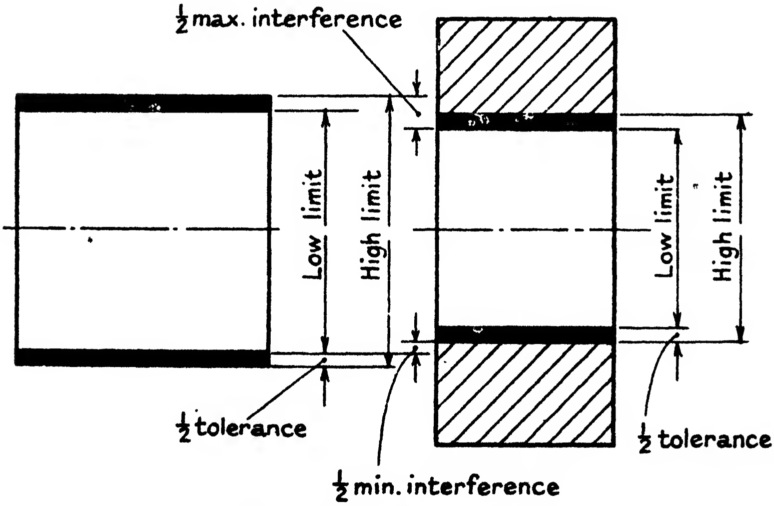


FIG. 43. INTERFERENCE FIT

Dimensioning by Limit System. The dimensioning of drawings by the limit system should be based on the following rules.

1. The dimensions must be interpretable in one way only.

2. The dimensions as given should be readily measurable by means of gauges.

3. Dimensions should be given from the most important surfaces, and from a machined face wherever possible.

4. Dimensions for the corresponding surfaces on mating parts should be given in a similar manner.

Limited dimensions should be expressed as shown in Fig. 44*a* with the larger dimension above the line and the smaller

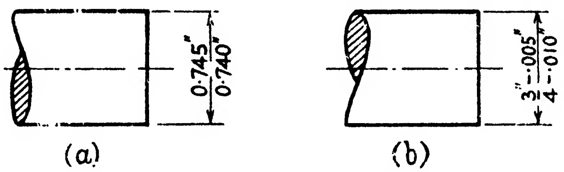


Fig. 44. Methods of Showing Limits

below. The method shown at (*b*) is sometimes used but is not recommended.

Dimensioning in Series. Care should be taken when dimensions have to be given for several parallel surfaces that

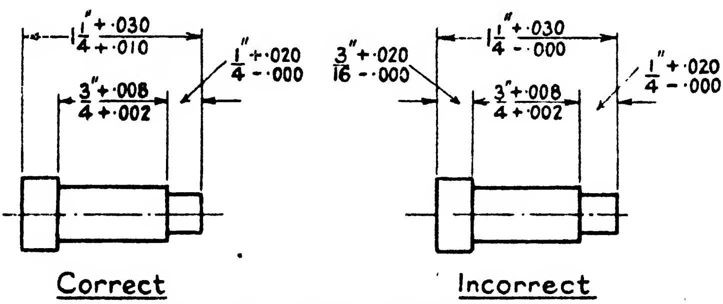


Fig. 45. Series Dimensioning

the important surfaces are correctly dimensioned and that no contradictory dimensions are given.

The pin in Fig. 45 shows a simple example of this type. The $\frac{3}{4}$ in. and $\frac{1}{4}$ in. dimensions are required to be to the given limits, whilst the length of the head is of minor importance. The left-hand sketch shows the correct method of dimensioning. The $\frac{3}{4}$ in. and $\frac{1}{4}$ in. dimensions are shown with suitable limits, and the overall length is also given to complete the series. The length of the head could have been given instead, but the overall length is the most convenient in practice.

In the right-hand sketch is shown a common but erroneous method of dimensioning this part. Supposing that if, when the

part had been made to these dimensions, the overall $\frac{3}{4}$ in. and $\frac{1}{4}$ in. lengths were measured, then it would be possible, taking the extreme limits, for the head to be—

High Limit. $+ 0{\cdot}030 - (0{\cdot}002 + 0{\cdot}000) = + 0{\cdot}028$ in.
Low Limit. $+ 0{\cdot}000 - (0{\cdot}008 + 0{\cdot}020) = - 0{\cdot}028$ in.;

i.e. the limit on the head could be $\frac{3}{16}$ in. $\pm$ 0·028 instead of as stated.

Similar disparities would occur if any other three dimensions were selected. For instance, if the three component lengths were worked to, the limits on the overall length would be—

High Limit. $0{\cdot}020 + 0{\cdot}008 + 0{\cdot}020 = + 0{\cdot}048$ in.
Low Limit. $0{\cdot}000 + 0{\cdot}003 + 0{\cdot}000 = + 0{\cdot}003$ in.

Limits in Special Cases. Care must be exercised in specifying limits on other than simple surfaces in order to conform with the rules that the dimensions shall be measurable and have only one interpretation, as shown in the following examples.

TAPERS. A taper has two variables, its angle and its width or diameter at a given position, and care has to be taken that both are distinctly defined. In Fig. 46 is illustrated a hole with a taper and parallel portion.

A method commonly used to fix the position of the taper is to specify the distance of junction of the parallel and taper portions, but it is practically impossible to measure this distance except very approximately, and such measurements would depend on the variation of the 0·875/0·870 diameter of the parallel hole. By specifying the distance from the end of the hole to a known diameter in the taper, not only is this difficulty overcome, but the taper is located more in accordance with the practical requirements. In the case illustrated a ball is used as these, accurately finished to within $\pm$ 0·0001 in. of the nominal size, are readily obtainable. It will be noticed that no tolerance is given on the diameter of the ball. This does not mean that the ball must not vary in size, although in actual practice such variations would be negligible compared with the 0·020 in. tolerance on the distance of the ball from the end, but that any variations in the size of the ball from the basic must be allowed for when checking the 0·320/0·300 dimension.

Fig. 46 (*b*) shows the same method of giving the position of a male taper, but in this case such a dimension would be checked by a suitable ring gauge.

The fixing of limits on the angle of a taper is rather more difficult. For unimportant tapers, a method similar to that shown in Fig. 46 (*c*) may be used, by giving a limited distance between two suitable basic diameters. When a taper is used as a means of fixing a wheel to a shaft to transmit a force between the two parts, it is essenital that the two tapers fit together for their full length. In other words, the limit which

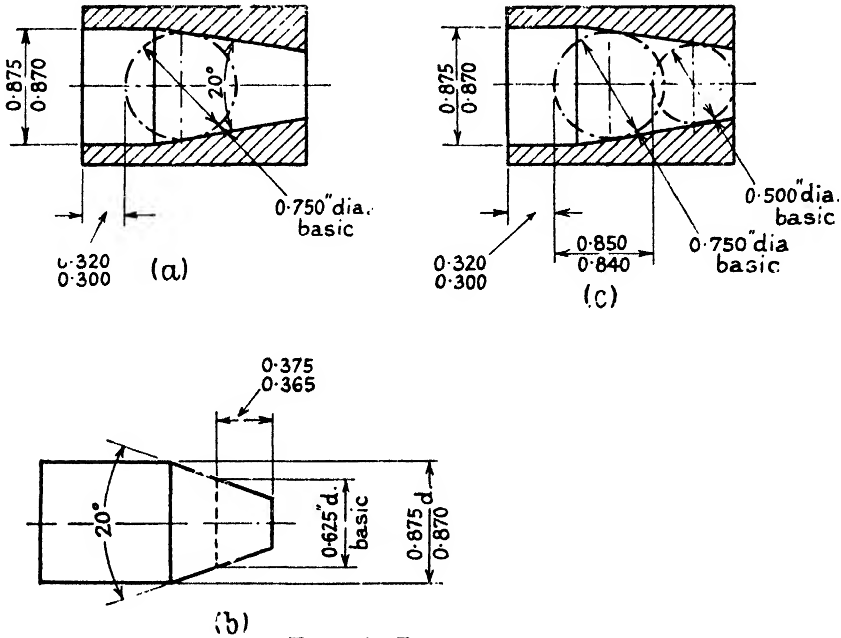


Fig. 46. Dimensioning

(*a*) Position of taper hole.
(*b*) Position of angle of taper shaft.
(*c*) Position and angle of taper hole.

may be allowed on the angle of the taper is negligible, and in production such tapers are usually tested by wringing with the gauge after marking with dye, the latter being removed uniformly along the length when the taper is correct.

The production and measurement of accurate gauges for the angle of tapers is not a very difficult matter, and in such cases the angle should be specified as "accurate."

Centre Distances. The relative positions of such regular figures as circles are best fixed by dimensioning the centre distances. Fig. 47 shows a simple example which depicts a plate with two holes at a nominal centre distance of 3 in. ± 0·005 in. apart, the holes having a diameter of 1 in. ± 0·005 in.

The usual method of checking the position of holes is to use a pin gauge similar in principle to that shown in the lower part of the figure, and if this gauge will enter the holes after they have been checked as being of the correct diameter, the centre distance is assumed correct; but obviously, what is being checked is not the position of the centres of the holes but the positions of their edges. The pins of the gauge must be

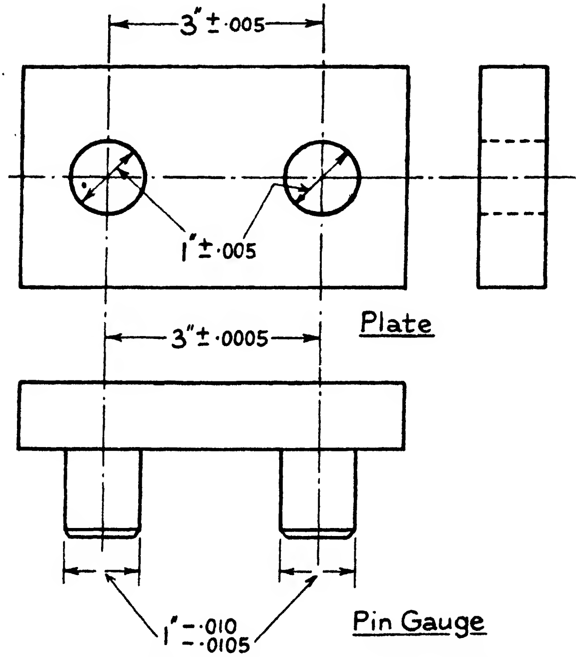


FIG. 47. PERFORATED PLATE AND PIN GAUGE

of such a size that they will allow the given tolerance on the centre distance for the smallest sized hole, and this is done by making the pins 0·005 in. smaller than the low limit on the hole. Should the holes be to the high limit, however, the possible tolerance on the centres will be increased to the sum of the tolerance on the holes, and the tolerance on the centres, i.e. the possible tolerance on the centres, might be $\pm$ 0·010 in. This is illustrated in Fig. 48. Although this could be avoided by dimensioning the position of the holes from the edges instead of the centres, it would be most inconvenient in practice, and if it is remembered that the given tolerance on the centres is likely to be increased by that on the holes, and allowance

made if necessary, there are no practical disadvantages in using this system.

FORMS. The difficulty of deciding the degree of accuracy to which a formed surface should be made is one that often confronts the manufacturer. Many forms are purely ornamental

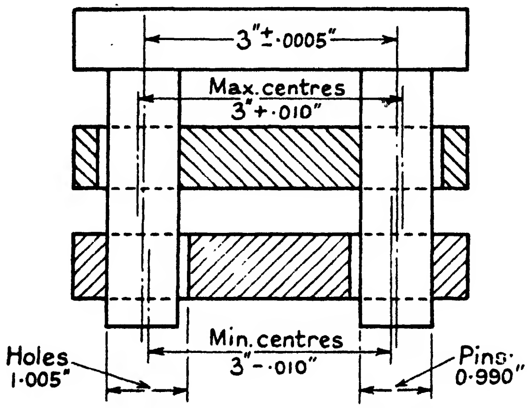


FIG. 48. PRACTICAL VARIATIONS OF CENTRE DISTANCES

and so long as they are pleasing to the eye and conform to one or two positional dimensions, the exact shape is immaterial.

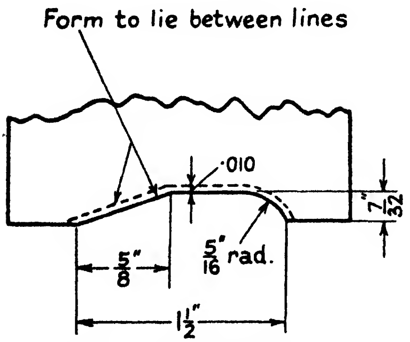


FIG. 49. DIMENSIONING THE LIMITS OF A FORM

Where such a formed surface is produced by a cutter, the checking of the cutter to some suitable limits is all that is required, and these may be shown as in Fig. 49. The double line represents the limit of form, and so long as it does not lie outside these lines it is accepted.

Where the form is important it is necessary to ensure that it can be checked easily to see if it conforms to the limits laid down. For small articles the best method, undoubtedly, is to project the profile of the part optically on to a screen, on which is drawn an enlarged outline of the form, with the allowed limits shown by a double line. For larger work the part and gauge should be suitably located, the latter being made to the maximum metal size, and the gap between it and the work

probed with a wire of the same diameter as the allowed tolerance. If the tolerance is exceeded, the wire will pass through.

The practice of fitting formed parts exactly to a templet is strongly to be deprecated, as it often results in time being wasted in achieving a quite unnecessary degree of accuracy.

Angular Dimensions. Angular dimensions are often given for the position of holes, etc., a typical instance being shown

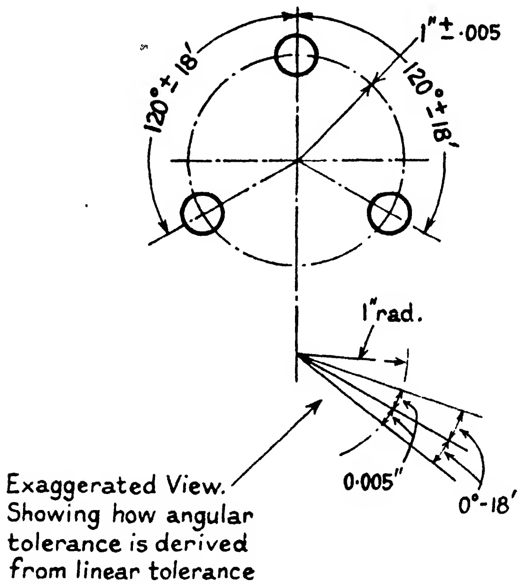


Fig. 50. Method of Showing Limits of Angular Positions

in Fig. 50. A limit of ± 0·005 in. is given for the pitch circle radius, and the limits on the angular position of the holes should be based on a linear tolerance of this amount.

The exaggerated lower view shows the method of calculating the angular limits. The centre of the hole may be ± 0·005 in. along the circumference of the pitch circle, at the extreme limits. The arc 0·005 in. subtends an angle of 0° 18′ at the centre of the 1 in. radius circle, and hence the limits on the angle are ± 0° 18′. The limits of the position of radial centre lines must be chosen to suit the particular application. The equivalent linear tolerances can be used as a basis. Fig. 51 shows this method applied to three slots cut in the end of a hollow shaft.

Types of Surfaces. Functionally, the surfaces of machine parts can be classed into three—

Non-mating Surfaces are those which do not come into

contact or close proximity with other surfaces. Usually the dimensions relating to them have tolerances as large as the manufacturing processes demand.

Clearance Surfaces are non-working surfaces, the position of which is important. The crests and roots of gear teeth are typical examples. Tolerances depend on the particular application.

Working Surfaces may be either *non-enveloping*, such as flat joints and slides, or *enveloping*, such as a hole and shaft.

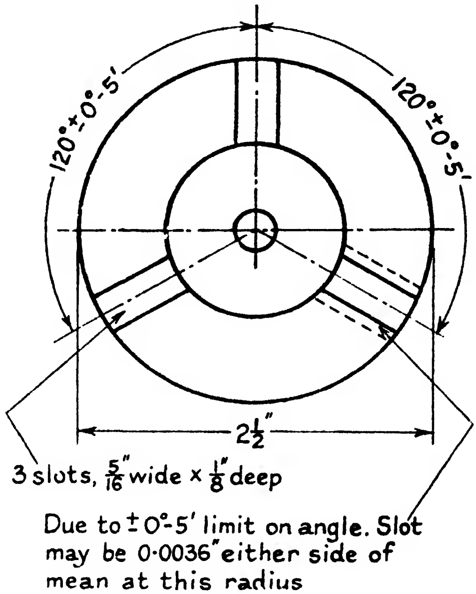


FIG. 51. METHOD OF SHOWING LIMITS OF ANGULAR POSITIONS OF SLOTS

In the latter case the parts, depending on their relative sizes, may have various fits, of which there are two main classes: *clearance fits* and *interference fits*.

A CLEARANCE FIT (Fig. 42) allows the parts to move relatively. The minimum clearance must allow at the least for a film of lubricant and for any errors of gauging which may occur. For parts exposed to adverse conditions, the minimum clearance may be such that rust and foreign matter do not interfere with the running.

The maximum clearance is a compromise which allows the maximum practical tolerance for manufacture without interfering with the functioning or life of the pair.

AN INTERFERENCE FIT (Fig. 43) is used when two parts are

to be permanently assembled together. The parts may be assembled by—

1. Forcing one part into the other.
2. Heating the outer part to expand it.
3. Cooling the inner part in liquid air or solid CO_2 to contract it.

Parts assembled by interference fits will distort in proportion to their stiffness. For instance, a thin-walled bush pressed into a hole in a thick plate would contract in the bore by about 60 per cent of the interference. This must be allowed for either by finishing the parts after assembly or by making the necessary allowance in the size of the parts before assembly.

The force required to separate parts assembled by an interference fit depends on—

1. The area of the surfaces in contact.
2. The amount of interference, provided that the elastic limit has not been exceeded. If the interference is such that the elastic limit is exceeded, the pressure required to separate may be lowered.
3. The condition of the surfaces before fitting together. Experiments have shown that whilst a certain amount of roughness of the surface, such as that given by an ordinary ground finish is immaterial, the presence of lubricants materially affects the force required to separate.

FORCE REQUIRED TO SEPARATE PARTS ASSEMBLED BY AN INTERFERENCE FIT

Results of experiments by R. Russell, B.Sc., A.M.I.Mech.E.* on test pieces 1½ in. diameter by 1¼ in. long, fitting in rings 3 in. outside diameter.

Lubricant	Type of Fit	Interference (in.)	Pressure Required to Separate (tons)
Rape oil . . .	Force	0·0006	4
Bayonne oil . . .	Do.	0·0006	9
Perfectly clean and dry .	Shrinkage	0·001	30–50 approx.
Rape oil . . .	Do.	0·001	8
As clean as possible† .	Expansion: liquid oxygen, −310° F.	0·001	4–5
Rape oil . . .	Do.	0·001	3

† The low figure is believed to be due to unavoidable film of ice on cooled part, which acts as a lubricant.

* *Proc. I.Mech.E.*, Vol. 125, p. 493 *et seq.*

The conclusions from these experiments were—

1. The degree of accuracy is of greater importance than the nature of the finish.

2. Excessive interference causing plastic flow leads to failing of grip.

3. The resistance to separation depends to a large extent on the surface film condition.

Systems of Assembly. INTERCHANGEABLE ASSEMBLY. When the limits are such that parts made to the extreme sizes will assemble together and function satisfactorily, the parts are said to be interchangeable. Interchangeable manufacture sometimes demands the use of fine tolerances, and expensive machines and machining operations; but for quantity production it is usually the most economical.

SELECTIVE ASSEMBLY. When the manufacturing tolerances are coarser than those necessary for satisfactory work, parts must be selected into sizes after manufacture. Selective assembly slows up production and usually necessitates the keeping of a stock of parts to ensure that there will be a sufficient selection of each range of sizes.

FITTING. When considerable variations are likely to occur during the manufacturing operations, it is often more economical to carry out machining operations during the assembly process. The procedure is usually confined to fairly simple operations, such as the drilling of bolt and dowel holes after the parts have been correctly placed together.

Fixing of Limits and Tolerances in Practice. Upon the correct choice of limits depends the successful operation of the machine, and the resulting tolerances decide the cost of manufacture and the type of machinery to be used.

Apart from the actual design of a machine, the fixing of the limits on the dimensions of the various parts is by far the most important feature, and should receive as much attention as any other, even to the extent of making up experimental models embodying the extreme limits which it is proposed to allow.

The tolerances to be expected when using various machining processes and methods of manufacture are given in Table V. These figures naturally vary with the type and age of the machines, skill of operatives and other factors depending on local conditions. They apply to dimensions up to and including 1 in. and they should be doubled for each 6 in. above 1 in. The first column gives the tolerances which can be obtained by normal working on modern machines without undue care.

Those in the second column can be obtained with a reasonable amount of attention being paid to the care and setting of tools.

The finest tolerances can usually only be obtained by taking two or more cuts so that the finishing tools remove only a minimum amount of metal. Parts produced to these tolerances may therefore be two or three times as expensive to produce as those made to the coarser ones.

The fits for enveloping surfaces such as holes and shafts may be divided for the purpose of fixing limits and tolerances, as follows—

Running Fits. *First Class.* (High speed shafts, etc.) When produced by precision methods, parts may be made to Newall limits or to British Standard Specification.

Second Class. (Parts not subject to continual running.) Table VI gives a series of suitable limits. The hole sizes are based on the use of reamers made to British Standard Specification.

Third Class. (Parts not subject to continual running and where play is not detrimental.) Where parts may be subjected to neglect and lack of lubrication, coarse fits may be preferable to closer ones. It is recommended in these cases that the male parts (e.g. shafts) be machined 0·001 in. to 0·008 in. below nominal and the hole be drilled with the next largest size drill, leaving a minimum clearance of 0·007 in., e.g. nominal size: $\frac{1}{4}$ in., shaft: 0·249 in./0·242 in. hole: drill with letter F Drill (0·257 in.).

Interference Fits. *First Class.* Parts must be produced by precision methods to Newall or similar limits, and it may be necessary to use selective assembly.

The limits recommended by the Hoffman Manufacturing Co. Ltd. for ball bearings and shafts are given in Table VII, and parts made to these limits may be assembled in practice with a minimum of selective assembly, as it is found that the majority of shafts approach the high limit and the majority of holes the low limit.

Second Class. Interference fits between parts produced by non-precision methods should be avoided where possible, and alternative methods of fixing used. Only parts which can be allowed a certain amount of distortion should be assembled by this means. A minimum interference of 0·001 in.–0·003 in. should be allowed, depending on the size, and the machining tolerances fixed as small as possible. One part should be provided with an initial taper to facilitate assembly.

Clearance Surfaces. Unless there is any reason to the contrary, the tolerances given in Column 1, Table V, may be used. A minimum clearance depending on the function of the surface must be allowed. It is usually advisable to allow ample clearance when dimensioning holes for ordinary bolts. Suggested clearances (on diameter) are: ·020 in. for B.A. screws, $\frac{1}{32}$ in. for screws up to $\frac{1}{2}$ in. and $\frac{1}{16}$ in. for larger sizes. For sheet metal work slots may be preferable to holes, the slots in adjacent sheets being at right angles to each other.

Non-mating Surfaces. The control of the dimensions relating to non-mating surfaces may be tackled in several ways; a method which is suitable for one factory may be quite unsuitable for another. Where the product is a well-known one and a rigid inspection system is not in force, it is often best to omit limits altogether on dimensions for non-mating surfaces, as it will be found in practice that the saving through reduced inspection amply compensates for occasional trouble due to inaccuracy. Where it is necessary to limit each dimension to facilitate inspection, the tolerances may be fixed on the estimated accuracy of the manufacturing process likely to be employed. The figures given in Column 1 of Table V, doubled and rounded off to a convenient figure, may be used. To fix tolerances too liberally may lead to carelessness and should be avoided; but where the system of limiting dimensions of non-mating surfaces is used, it is best to authorize the inspection department to make concessions where it is obvious that no harm can result by so doing. Another method is for the dimensions relating to non-mating surfaces to be filled in without limits, and a note placed on the drawing giving the limits for all dimensions not otherwise specified. On some classes of work it is sufficient to give a general limit of $\pm$ 0·005 in. or $\pm$ 0·010 in. These limits are, however, usually found unnecessarily irksome in practice and are often disregarded. A variation which has been found successful is to grade the tolerances with the size of dimension. For example—

Dimension	Limit
$\frac{1}{4}$ in. and under	$\pm$ 0·010 in.
Over $\frac{1}{4}$ in. ,, $\frac{1}{2}$ in.	$\pm$ 0·015 in.
,, $\frac{1}{2}$ in. ,, 1 in.	$\pm$ 0·020 in.
,, 1 in. ,, 2 in.	$\pm$ 0·025 in.
,, 2 in.	$\pm$ 0·030 in.

These tolerances are suitable for ordinary machining processes. For castings they would be larger.

Screw Threads. The tolerances fixed for screw threads are important owing to their effect on the efficiency of the mechanism, ease of assembly and cost of thread production. Unless a threaded part is highly stressed the general practice should be to allow fairly wide tolerances such as those given for Free Fits in B.S.84. Screw threads of Whitworth form.

The tolerances for taps are given in B.S.949 and as the majority of internal threads are produced by tapping their accuracy will depend on the grade of tap used. Although at first sight it may seem possible to obtain comparatively accurate internal threads at small extra cost by buying first grade taps, it must be remembered that these will wear to the minimum size more quickly, and unless inspected frequently, may be a source of trouble in assembly.

Recommended tapping drill sizes are given in Table VIII, page 137. Although these sizes are rather larger than those often given it will be found that they give the most satisfactory results.

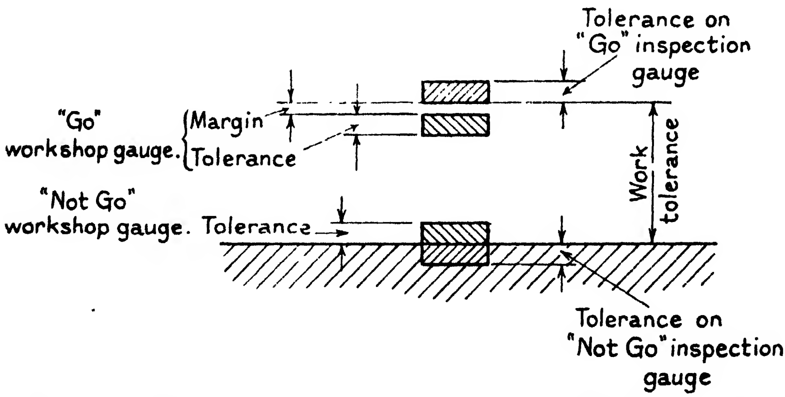


FIG. 52. DIAGRAM SHOWING RELATIVE SIZES OF WORKSHOP AND INSPECTION GAUGES

Gauging and Inspection. The system of inspection employed must be considered when fixing limits, tolerances, and clearances.

All important surfaces should, of course, be dimensioned in such a way that they may be easily and accurately gauged. Fig. 52 shows the relationship on the sizes of the gauges to the limits on the work. The tolerances on the gauges are usually about $\frac{1}{10}$ of that allowed on the work, and in the case of the

workshop gauges a small allowance for wear is also economically justified on the "Go" gauge. When the gauge is new, this allowance reduces the tolerance on the work. The inspection gauges, especially when dealing with parts which may have to be made by a contractor, must be capable of passing all parts made within the specified limits. Any allowances on the inspection gauges must, therefore, be outside the limits given for the part, and when allowing clearances the possibility of slightly full parts being passed must be allowed for.

CHAPTER VI

STANDARDIZATION AND SPECIALIZATION

Standardization. The importance of standardization is now generally recognized, and the British Standards Institution has been in existence for some years, its object being to issue standard specifications for materials, design, tests, etc., with the co-operation and approval of the interested parties. Other technical bodies also issue specifications for the use of their members, as for instance, the Institution of Automobile Engineers.

Specifications may be in the form of suggestions. They may lay down requirements of quality or design which should be adhered to for satisfactory functioning, or they may seek to standardize design so that the products of the several manufacturers shall be interchangeable.

It is unfortunate that by seeking to standardize a product too early, progress may be hindered, and by leaving it until later, the amount of capital invested by various manufacturers in plant to produce their own designs may prove a serious obstacle to the adoption of a standard pattern.

Besides the standardization of complete components, it is also possible to standardize details of construction which may be used by designers with confidence.

Specialization. It is now no longer economical for each manufacturer to attempt to produce all the parts required from the raw material. Parts and self-contained units which are in reasonably wide demand are now produced by firms specializing in their manufacture, and there is no doubt that considerable advantages are gained from this practice. The purchaser obtains the benefits of research and experience at a nominal cost, and owing to the larger quantities of the same pattern produced, the actual manufacturing costs are less and distribution of spare parts is facilitated.

At the present time there are certain components which have been so developed by specialists—as for example, ball and roller bearings—that it would not be worth while individual manufacturers attempting to produce them for their own use, even if an inferior article were acceptable.

Unless there are important reasons to the contrary, specialized

articles can usually be incorporated to advantage by the designer, as a basis for an efficient and economical design.

Specialized products of more general interest include—

Engines (oil and petrol).
Electric motors.
Clutches (friction).
Pumps.
Bearings.
Oil seals.
Gear boxes (worm, spur, change speed).
Chains.
"V" rope drives.
Fastening devices.
Instruments.

Screws and Screw Threads. Many systems of screw threads have been standardized by various bodies, some intended for

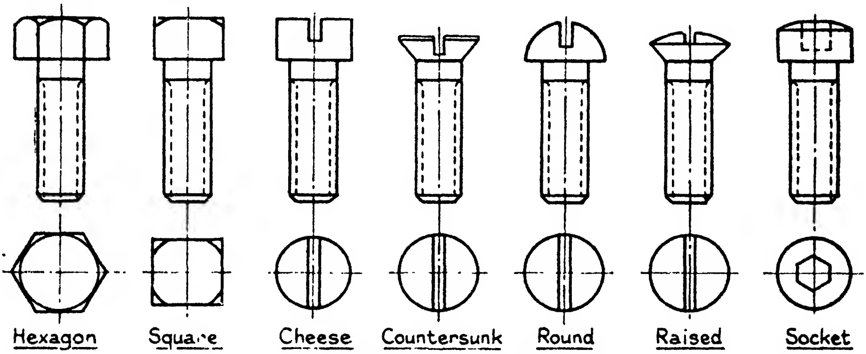


FIG. 53. TYPES OF SCREW HEADS

universal use and others for special purposes. Full details of these will be found in *Machinery's Screw Thread Book.**

For light engineering it is recommended that the even B.A. (British Association) sizes be used for screws smaller than $\frac{1}{4}$ in. For $\frac{1}{4}$ in. and larger the B.S. Fine system should be used but screws larger than $\frac{1}{2}$ in. are seldom used. Large threads on components are usually made with a fine pitch, 2ft, 16, or 14 threads per inch. For pipes and for making joints subject to fluid pressure B.S. Pipe threads should be used. These threads have a finer pitch than the Fine series and are sometimes used on general work on this account.

The more common types of screw heads are shown in Fig. 53. Screws with these heads are obtainable commercially in the standard threads and in various lengths.

.* The Machinery Publishing Co.

Screws with slotted heads are rarely made over ½ in. diameter, as it becomes necessary to use a spanner to tighten them when larger than this.

Hexagon nuts are used almost invariably.

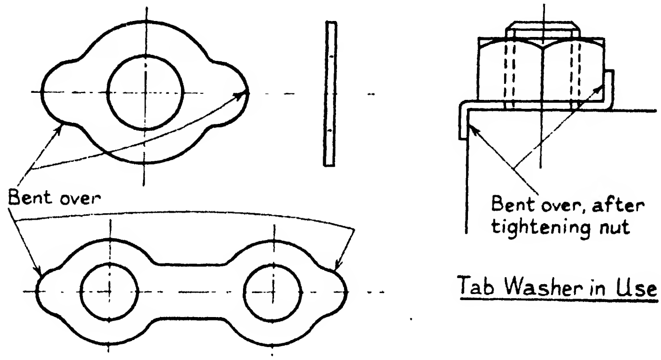


FIG. 54. SINGLE AND DOUBLE TAB WASHERS

Nut Locking Devices. Where it is essential that a nut should not work loose, even under severe vibration, a mild steel tab washer as shown in Fig. 54 should be used. In the single type one tab is bent over a suitable flat face on the boss, and the other against one of the flat faces of the nut. Tab washers for two or more nuts require turning over on the nuts only.

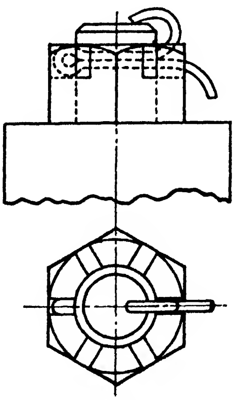


FIG. 55. METHOD OF RETAINING NUT WITH SPLIT PIN

Where it is not practicable to screw the nut up tight, a slotted nut and split pin, as shown in Fig. 55, can be used, as this has the advantage of being easier to dismantle.

The lock washers shown in Fig. 56 are cheap and may be used where the slackening or loss of the nut would not be followed by serious consequences. The double coil washer is the most efficient where the parts being screwed together may take a permanent set under the pressure.

Rivets and Riveted Fastenings. Riveting can be used profitably where a joint will not need to be disturbed.

For joining sheet metal, rivets made from soft wire headed at one end are used. The shape of head for general use is the round one shown in Fig. 57 (*a*). The head of the other end of the rivet, formed after assembly, may be of any of the shapes

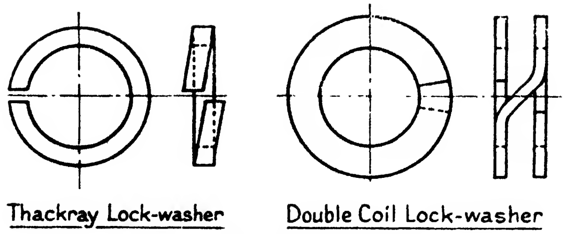


FIG. 56. LOCK-WASHERS

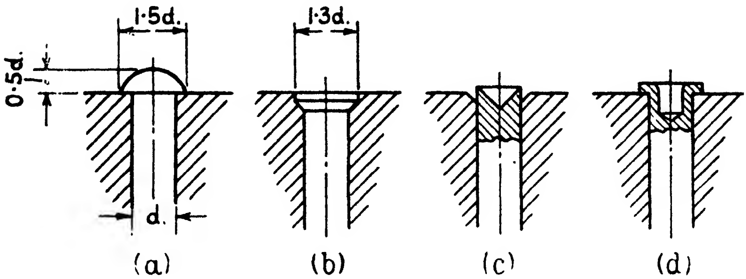


FIG. 57. RIVET HEADS

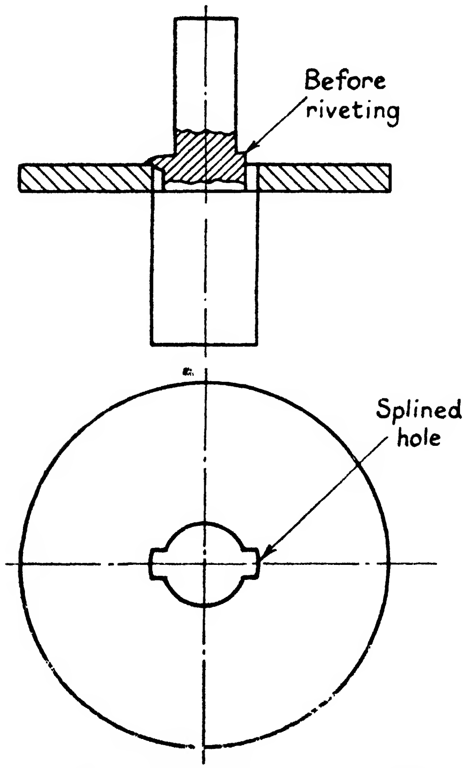


FIG. 58. FIXING SPINDLE TO PLATE

shown in the figure. The round one is the strongest and should be used where possible, whilst the countersunk head (*b*) is used where space is limited or a round head would be objectionable. Shapes (*c*) and (*d*) are used where it is desirable to form the head with as little pressure as possible as, for instance, with fragile articles.

The riveting process may be employed for fastening spindles, etc., to plates, as in Fig. 58. By splining the hole, or indenting it with a pyramid-shaped punch before riveting, any possibility of relative rotation between the two parts is prevented, as the metal is forced into the splines or indents during the riveting process and so forms a key.

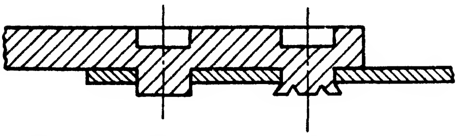


FIG. 59. SOLID RIVETS AND DOWELS

For attaching a thin to a thick sheet, the method shown in Fig. 59 may be used. The parts are placed together in the correct relationship and the rivets are formed by forcing the metal through the holes in the thinner part by punches. The heads of the rivets are then burred over. Similar projections may be used as dowels.

Drive Fastenings. The difficulty of making drive fits, unless the parts are made to fine limits, has led to the development of drive fastenings suitable for non-precision methods. An example of this type is the Parker-Kalon Quick Drive Screw which is illustrated in Fig. 60. It is intended for permanently fastening sheet metal to angles, castings, etc. The screw is hardened and has a thread with a steep helix angle. On forcing the screw into an ordinary drilled hole, it cuts its own thread, slight irregularities in the sizes of the hole and screw not affecting the holding power.

FIG. 60. PARKER-KALON QUICK DRIVE SCREW
(*Guest, Keen and Nettlefolds, Ltd.*)

Permanent drive fits may be made as shown in Fig. 61 by knurling the outside of the inner part except for a small distance from one end, which acts as a guide when assembling. The hole should be drilled to a size slightly larger than that of the male part before knurling. It is, of course, essential that only one of the parts, preferably the inner, be hardened, but satisfactory results are obtained if both parts are soft.

Keys and Driving Methods. The more important methods for transmitting power between a shaft and gear, pulley, etc., mounted on it are shown in Fig. 62.

The square key at (*a*), which is fitted into a flat-bottomed slot with rounded ends, milled in the shaft, is a satisfactory method and can be used for transmitting a considerable load.

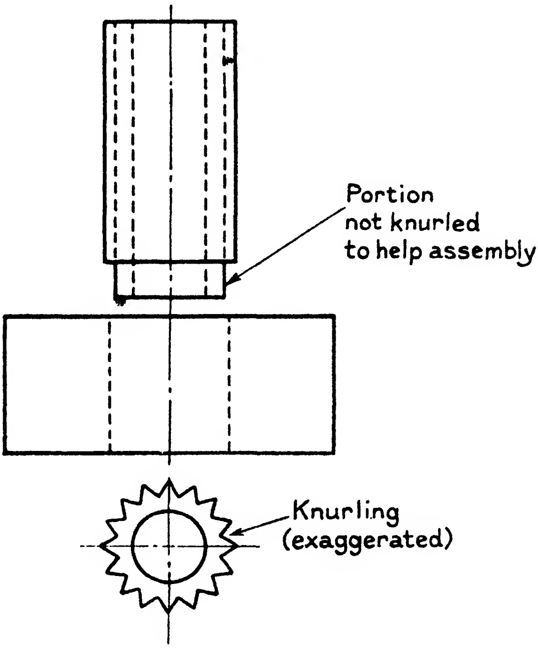


FIG. 61. KNURLED DRIVE FIT

It needs, however, to be carefully fitted, and is not suitable for use when the gear slides along the shaft.

The Woodruff key, shown at (*b*), has the advantages of simplicity and cheapness, as not only are the keys and keyways easy to make, but fitting can be dispensed with. The amount of power that can be transmitted is limited by the size of key that can be used, but it is sufficient for many purposes. The gear must not slide on the shaft.

Where gears, etc., must be able to slide on the shaft, the splined shaft shown at (*c*), is now universally adopted. The shaft splines are cut on a milling or gear hobbing machine although, if the latter, care must be taken with the design. The hole is cut by broaching. If, as is often the case, the parts are hardened, the inside of the hole is subsequently ground on

a cylindrical internal grinding machine and the bottoms and sides of the shaft splines are also ground. A clearance is

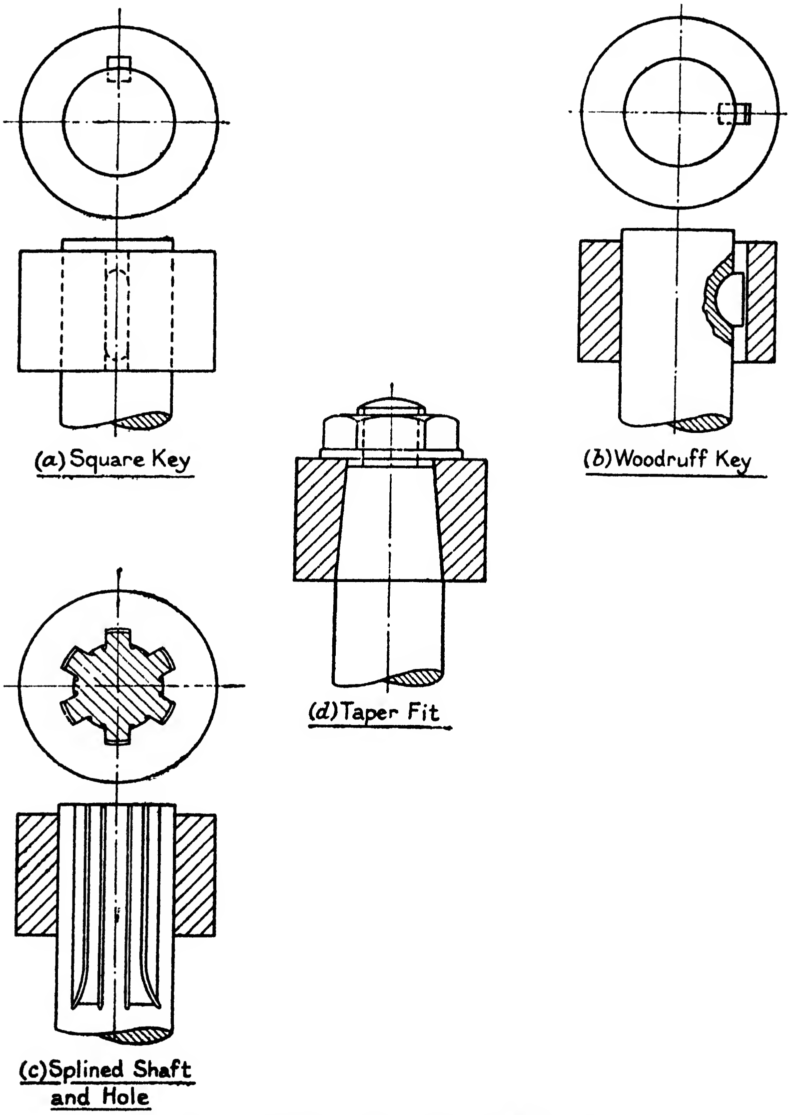


FIG. 62. KEYS AND DRIVING METHODS

allowed between the top of the shaft splines and the bottom of those in the hole.

Splined shafts and holes are now used extensively instead of loose keys, where dismantling and assembly by the user may be

necessary, as they are less likely to suffer from ill-treatment and there are no loose parts to be mislaid.

For some purposes the taper fit shown at (*d*) is to be preferred. By slackening the nut and loosening the taper, the parts can be set in any angular position desired, and when tightened up the two parts are fixed together without any possibility of shake or play. Taper fits are frequently used in conjunction with a loose key where a fit is required which will be free from play, and capable of carrying a load without the risk of rotation taking place.

Taper splines are used for very important drives, such as that from an aeroplane engine crankshaft to the propeller boss.

Anti-friction Bearings. Ball and roller anti-friction bearings are almost exclusively manufactured by specialist firms. These bearings have several advantages over the plain type which make them preferable for most applications where loads and speeds are of any appreciable magnitude.

The advantages of the anti-friction bearing are—

1. Absence of measurable wear when properly mounted and lubricated, even after lengthy service.

2. Low co-efficient of friction. The limiting static friction may be only about $\frac{1}{700}$ of that of plain lubricated bearings under heavy loads, and the running friction about $\frac{1}{10}$. There is little difference between the limiting static and running friction for ball and roller bearings.

3. The length of bearing is far less than that of a plain bearing intended for a similar load.

4. Grease lubrication may be used. As grease is easily retained in the bearings, refilling with lubricant is only required infrequently, with a consequent saving in cost.

The disadvantages of anti-friction bearings are—

1. Large diameter compared with plain bearings. (This may be overcome in certain cases by using needle roller bearings.)

2. Difficulty of mounting in certain cases, such as crankshafts, where split bearings have to be used.

The more popular types of anti-friction bearings are illustrated in Fig. 63, and these cover all but exceptional applications.

Deep Groove Ball Bearings. (Fig. 63 (*a*).) This is a most useful bearing and one which will take both journal and thrust loads in either direction. It may be used, as shown in Fig. 64 (*a*) in pairs, both bearings taking journal load and one being

clamped sideways to cater for thrust. The thrust load should always be applied to the bearing with the smallest journal load. A roller bearing may be used instead at the more heavily loaded end of the shaft, as shown in Fig. 64 (*b*).

Mounted directly alongside a roller bearing, a deep groove

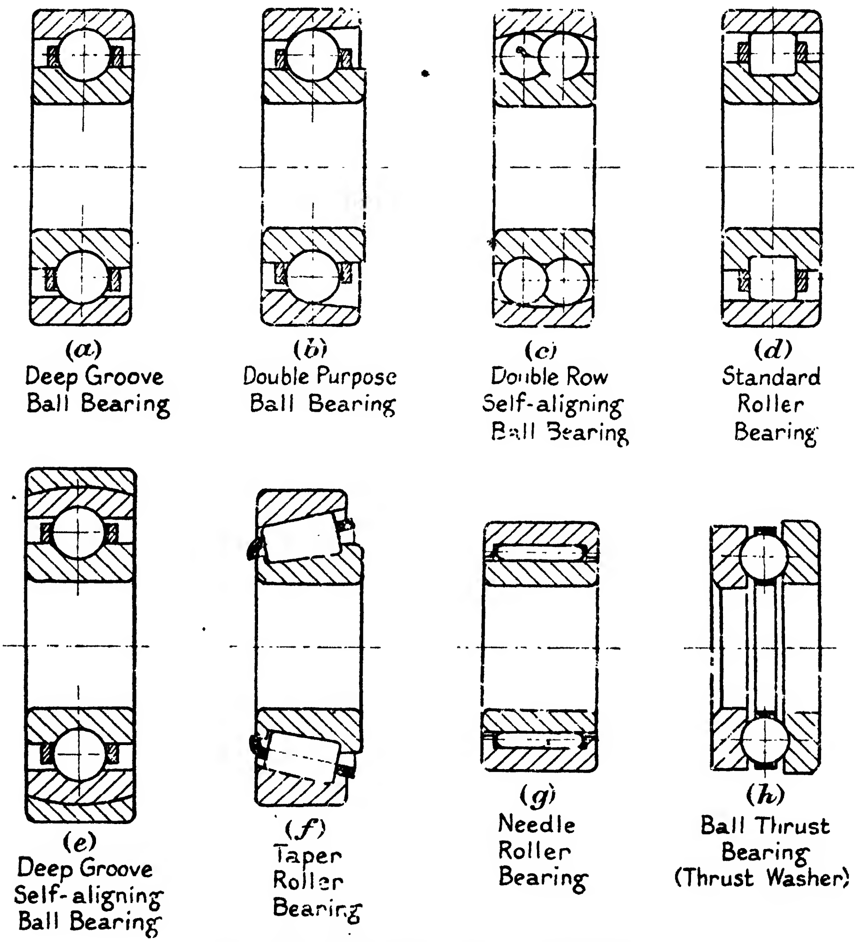


FIG. 63. BALL AND ROLLER BEARINGS

bearing may be used to take thrust only, but, in this case, the outer race of the bearing is made smaller than standard to ensure that no journal load is carried, as in Fig. 64 (*c*).

DOUBLE-PURPOSE OR COMBINED JOURNAL AND UNIDIRECTION THRUST BEARINGS. (Fig. 63 (*b*).) These bearings are intended to take a journal load and thrust in one direction

only, and are, therefore, usually mounted in pairs, unless the shaft is vertical, when one, to support the weight, may be sufficient. A typical application is shown in Fig. 64 (*d*) for supporting a worm shaft. The simplicity of the mounting should be noted. The caps retaining the bearings are adjusted to give a small amount of end play to the bearings. These bearings, if desired, may be used in pairs at one end of a shaft, to deal with thrust in both directions and the journal load at that end, the other end of the shaft being carried by another bearing.

DOUBLE-ROW SELF-ALIGNING BALL BEARINGS (Fig. 63 (*c*).) This type of ball bearing has the outer track ground spherical so that, if the bearings are used in pairs, a considerable amount of misalignment between the bearing housings can be allowed. Unfortunately, the capacity of this type of bearing is comparatively small, although it is suitable for both journal and thrust loads.

STANDARD ROLLER BEARINGS. (Fig. 63 (*d*).) These bearings are interchangeable with ball bearings and have 50 per cent to 70 per cent greater load carrying capacity for the same external dimensions. They are not usually recommended for thrust loads, although bearings with shoulders on the inner race also can be obtained and these may be used for light thrust loads and for location.

Applications are shown in Fig. 64, and it will be noticed that a ball bearing is provided in each case to take the thrust load.

SINGLE-ROW BALL AND ROLLER SELF-ALIGNING BEARINGS. (Fig. 63 (*e*).) These bearings are simply standard ball or roller bearings with the outside ground spherical and fitted into a housing. They have the same journal capacities as the corresponding plain bearings, but are not suitable for definite thrust loads. They are useful for mounting long shafts, where the flexure of the shaft would cause considerable strain on a fixed bearing.

TAPER ROLLER BEARINGS. (Fig. 63 (*f*).) This type of bearing is not unlike the double purpose bearing (Fig. 63 (*a*)) in its application, but it has a greater load carrying capacity. By a simple adjustment any play due to wear which may develop can be taken up. A typical application is shown in Fig. 64 (*g*).

NEEDLE ROLLER BEARINGS. (Fig. 63 (*g*).) These bearings have rollers, as their name implies, with a small diameter compared with their length. The advantages of this type of bearing are that it is comparatively cheap and takes up little more room than a plain bearing. It is, however, unsuitable for

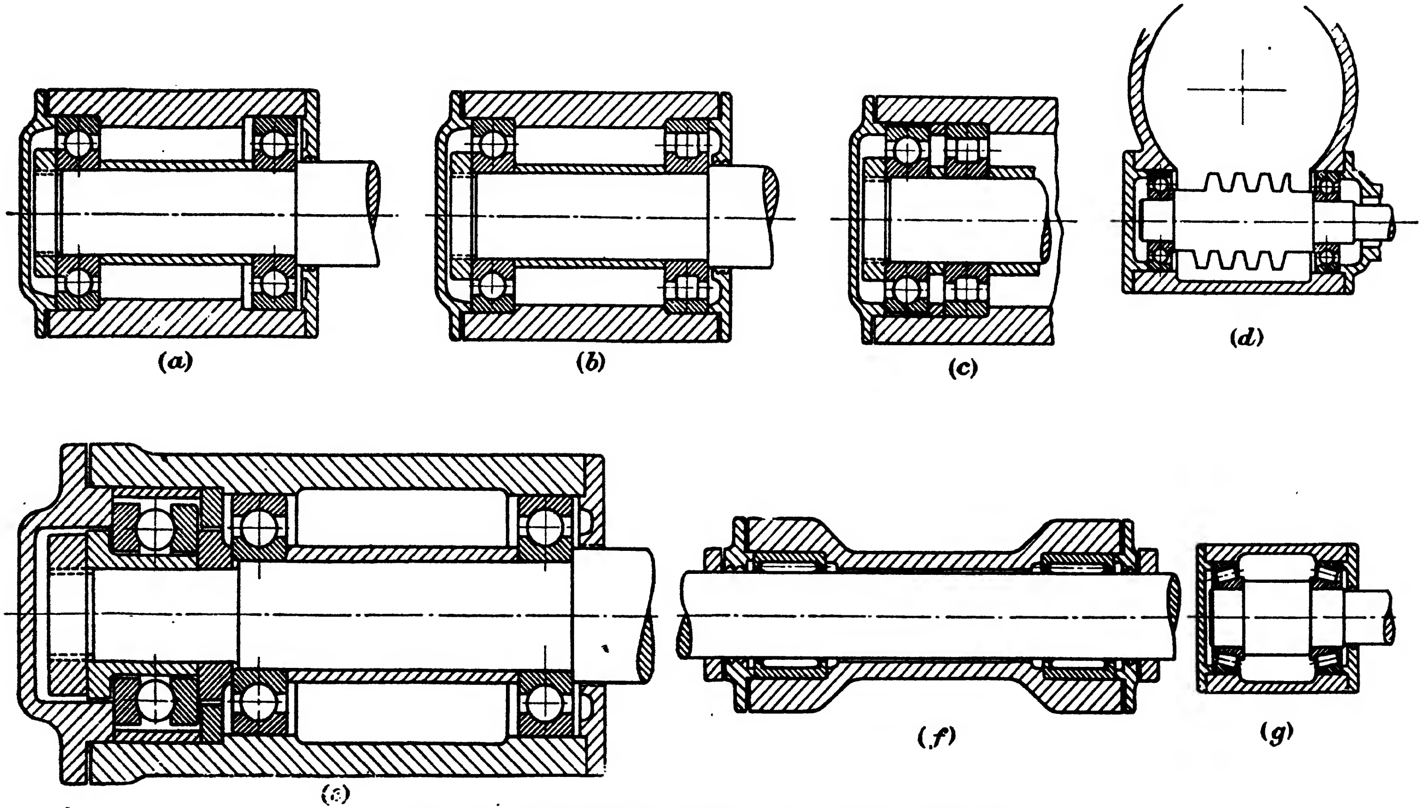


FIG. 64. APPLICATIONS OF BALL AND ROLLER BEARINGS

high speeds and heavy loads, but is especially suitable for oscillatory movements. By using the shaft or housing (or both) as tracks, instead of having a special race, both cost and space can be reduced.

A needle roller bearing applied to a heavy vehicle brake cross shaft is shown in Fig. 64 (*f*).

Ball Thrust Washers. (Fig. 63 (*h*).) Several patterns of this bearing are made, the one shown being the most useful. It is suitable for thrust loads at comparatively low speeds and should always have a journal bearing close to it to ensure correct alignment. At high speeds the balls tend to fly out due to centrifugal force and this reduces the capacity of the bearing considerably.

By means of the arrangement in Fig. 64 (*e*) this bearing may be used to take thrust in both directions. When the thrust is reversed, the shaft moves slightly endwise and so transfers the thrust from one set of faces to the other.

Fitting Anti-friction Bearings. The rotating race of the bearing must be a tight fit on its seating and can with advantage be clamped against a shoulder by, for example, a nut. It is essential that this race should not come loose in service as this will cause the failure of the bearing. The stationary race should be a push fit and unless used for location purposes, should be free to move endwise to align itself with the rotating race. The outer race of standard roller bearing (Fig. 63 (*d*)) if stationary, may be clamped or not, as desired.

Recommended limits for seatings are published by the bearing manufacturers.

Oil Retaining Bearings. For lightly loaded bearings and for those which operate intermittently, phosphor bronze bearings made by powder metallurgy are widely used. These bearings are porous and absorb about 40 per cent of their volume of oil which is available for lubricating the shaft whilst running. This method of production ensures that the bearings are sufficiently accurate for most purposes without machining, which, in any case is not recommended as it clogs the pores. Where the duty is not too onerous no further oil need be added to the bearings during the life of the machine. When additional oil is needed an oil passage can be lead to the *outside* of the bearing, or it can be surrounded by a cavity filled with oil-soaked waste. There are a large number of standard sizes of plain and headed bushes and washers and where the quantities are large enough special designs can be made.

Bearing Seals. With many bearings, but especially with anti-friction bearings, it is necessary to retain oil and grease and exclude dirt, water and other foreign matter. Felt washers, soaked in tallow, may be used, as shown in Fig. 65 (*a*). The washer is let into a groove in the bearing cover and has a hole

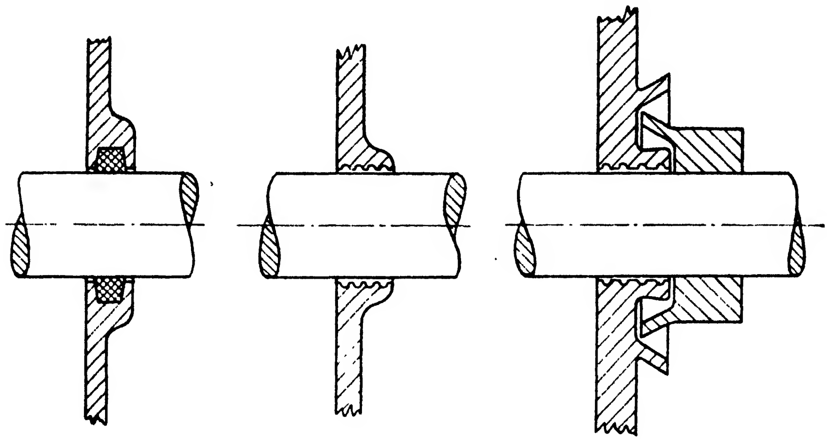


FIG. 65. SEALS FOR BALL AND ROLLER BEARINGS

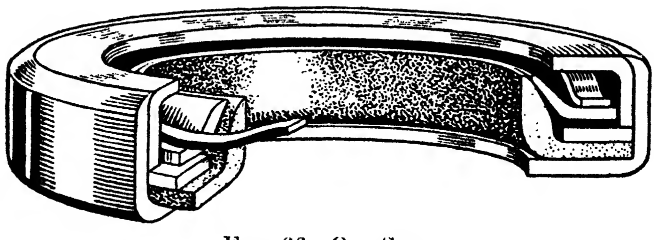


FIG. 66. OIL SEAL
(*Chas. Weston & Co. Ltd.*)

slightly smaller than the shaft. This method is useful for retaining oil, if not too thin, as in gear boxes.

A simple method is that shown in Fig. 65 (*b*). A number of grooves are turned in the bore of the cover which become filled with grease from the inside and thus prevent the entry of dirt.

The slinger, shown at (*c*) Fig. 65, may be used to prevent water or liquid finding its way into the bearing, or in certain cases, oil finding its way out. The slinger is obviously most effective when the shaft is rotating at a high speed.

A proprietary oil seal is shown in Fig. 66 and this consists essentially of a leather sleeve which is pressed against the shaft

by a spring loaded ring. Such a seal is very efficient and, being obtainable in a wide range of sizes at a reasonable price, is often used in preference to any other method.

Circlips. The axial location of gears, ballraces, shafts, etc., can often be conveniently and cheaply effected by circlips sprung into grooves machined in the shaft or housing. The necessity of providing collars, shoulders, threads and other

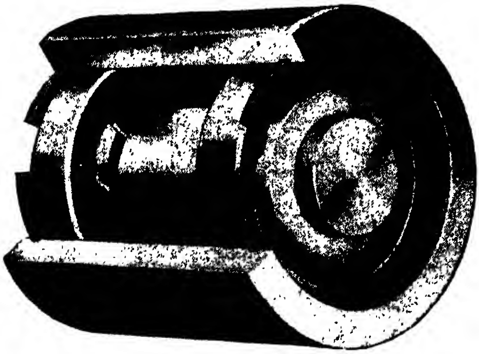


FIG. 67.

locating elements is obviated and assembly is simplified. It must not be overlooked, however, that the grooves may act as stress raisers (see p. 8) and this may make circlips undesirable on important parts. The Seeger circlip is widely used and its method of application is shown in Fig. 67. It will be seen that there are both internal and external types and these spring into rectangular grooves machined in the housing or shaft. The Seeger circlips are stamped from sheet steel and are shaped so that the periphery always remains circular; a most important factor in determining their efficiency. The clips are available in sizes from $\frac{7}{16}$ in. to 8 in. diameter, the material thickness being ·040 in. for the smaller sizes increasing to ·200 in. for the larger, and will withstand any axial thrust usually encountered.

CHAPTER VII

DRAWINGS AND SPECIFICATIONS

The preceding chapters have dealt with the fundamentals underlying the design of mechanical products which it is intended to make on a repetition basis. The preparation of the information necessary for the manufacture and assembly of the finished article will now be dealt with.

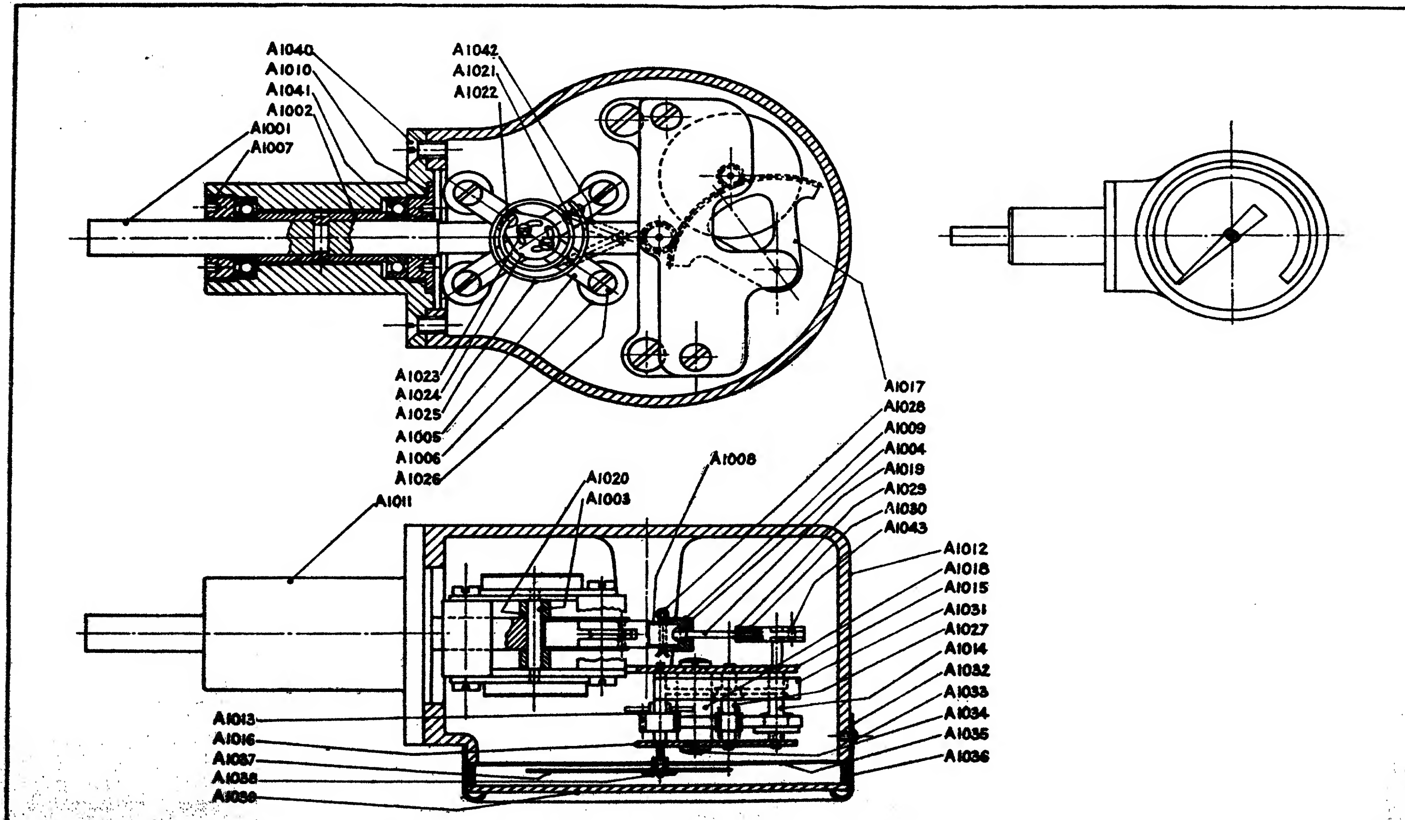
When the general details of the new design have been decided upon, an estimate should be prepared of the quantities which will be sold, and as this may depend on the selling price a maximum production cost may also be stipulated. With these as a basis, the design is then considered in detail, with a view to arriving at the most economical proposition. For instance, it may be necessary to decide whether a certain part shall be made from an iron casting or a zinc die casting. Up to a certain quantity the former will be cheaper, whilst above that quantity, after allowing for the capital cost of the dies, the latter will give the cheapest construction. This, of course, will necessitate the accurate estimation of the relative costs of the two methods.

At this stage any interested parties should be consulted—the suppliers of raw materials and semi-finished components may be asked to suggest alterations which would improve or facilitate the manufacture of the product, and the manufacturing and inspection departments may wish certain points attended to which they have found desirable when making similar products. Such consultations are of great value and often save unnecessary expense being incurred when manufacture commences.

The information issued by the Design Department for the benefit of the Production Departments includes the following—

1. Assembly Drawings.
2. Schedule of Parts.
3. Drawings of Component Parts.
4. Specifications of Component Parts and Completed Product.
5. Inter-operation Drawings of Components.

The actual information given will depend on the type of product and the requirements of the individual factory organization.



TITLE. ASSEMBLY DRAWING OF 5" TACHOMETER	SCALE 1:1 DR. TR. CH.		ASSEMBLY Nº A.1.

The following detailed study will show the methods usually adopted.

The tachometer, Fig. 68, is used for indicating the speed of Diesel engines and small turbines. It is manufactured in quantities of 100 at a time and it is estimated that about 5000 will be made before it becomes necessary to re-design. This latter figure is only an assumption, as factors causing the design to become obsolete cannot be foreseen and are outside the manufacturers' control.

The tachometer is fitted to the engine by the spigot A1011, which may sometimes be required in other diameters to that shown to suit various engines. The drive is taken through the spindle A1001, which carries the cross pendulums and runs in two double-purpose ball races. The rotation causes the pendulums to fly out against the action of the springs, and the motion is transmitted through the links to the quadrant, which meshes with the pinion carrying the pointer. The pointer indicates the speed of rotation on the suitably graduated dial. The inertia wheel A1031 is fitted to damp out any oscillations of the pointer which might be caused by sudden or periodic changes of speed.

Assembly Drawings (Fig. 68). These should not be too elaborate, the important point being to show clearly the method of assembly, so that it can be followed easily by the workman. It may sometimes be desirable to give instructions for setting, and occasionally dimensions which cannot be included in the detail drawings.

Each part should be shown at least once and identified by number, as shown.

Schedule of Parts (Fig. 70). It is essential that this be compiled with great care, as it is from the parts list that the orders are issued for the manufacture or purchase of the component parts and materials. Even the paint is included in some systems of scheduling, but the inclusion of such items will depend on the circumstances, and they are often omitted.

Drawings of Component Parts. Each component part should be drawn out on a separate sheet which is printed with the title block and border. A lay-out based on B.S. 308: 1943, Engineering Drawing Office Practice is given in Fig. 71. Photoprints of each drawing are issued to all departments concerned and for workshop use are mounted on plywood or stiff cardboard. Workshop drawings should be kept in a special

5 in. TACHOMETER			ASSEMBLY NO. A1	
PART NO.	NAME	NO. SET	MATERIAL	REMARKS
A1001	SPINDLE	1	FREE CUTTING MILD STEEL	
A1002	SLEEVE	1	DO.	
A1003	PENDULUM SPINDLE	1	DO.	
A1004	BALL	1	STEEL BALL	$\frac{3}{16}$ In. DIAMETER
A1005	PENDULUM ARM	4	HARD BRASS	
A1005	PENDULUM WEIGHT	4	FREE CUTTING BRASS	
A1007	CAP	1	DO.	
A1008	PISTON	1	FREE CUTTING MILD STEEL	
A1009	PISTON CAP	1	DO.	
A1010	CAP	1	DO.	
A1011	SHANK	1	CAST IRON	
A1012	CASE	1	ALUMINIUM DIECASTING	
A1013	PINION	1	STAINLESS IRON	
A1014	AXLE	1	FREE CUTTING MILD STEEL	
A1015	SIDE PLATE	1	HARD BRASS	
A1016	SIDE PLATE	1	DO.	
A1017	QUADRANT	1	DO.	
A1018	PILLAR	2	FREE CUTTING BRASS	
A1019	BALL ROD	1	MILD STEEL	

Fig. 70. Part of Schedule of Tachometer Parts

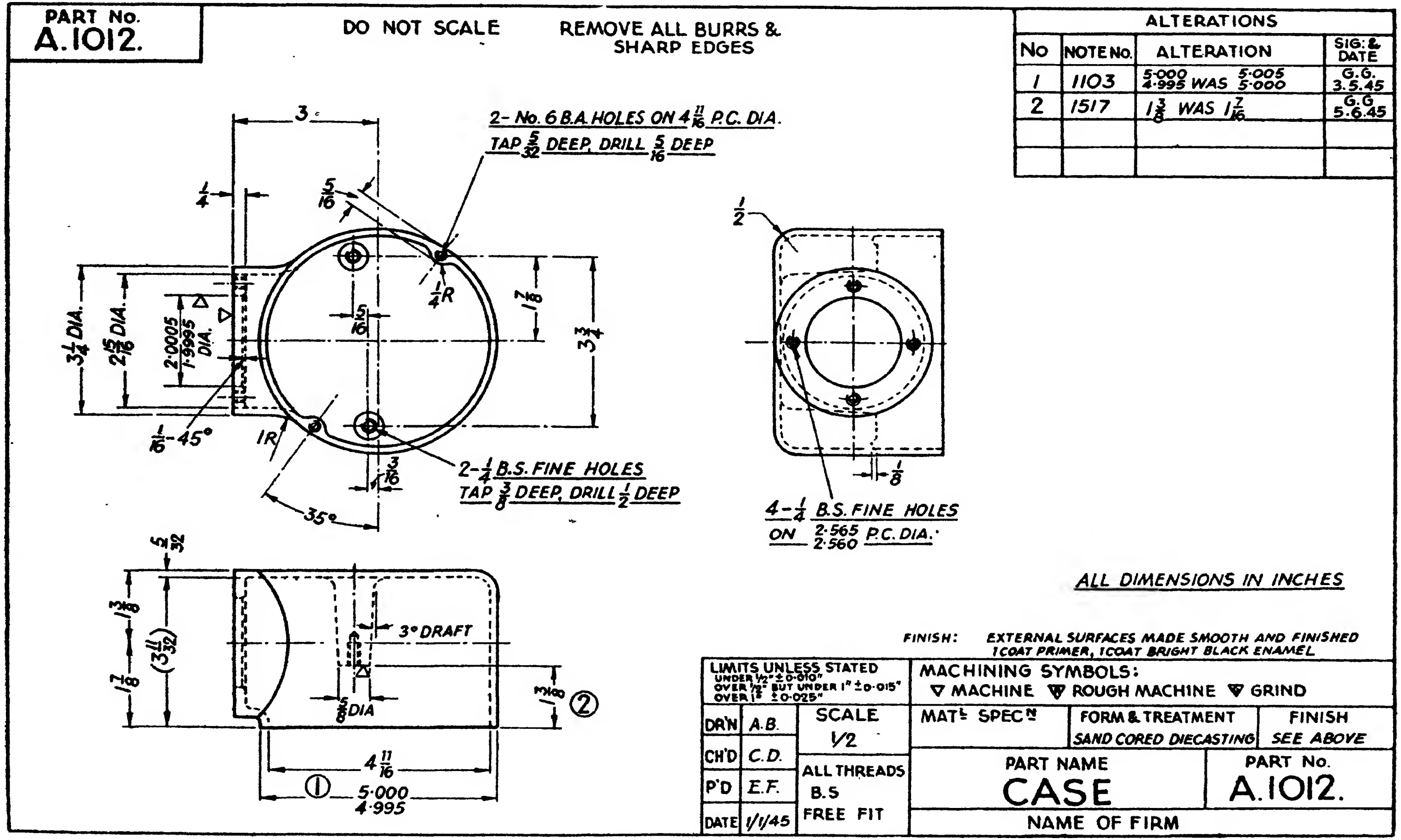

PART No. A.1012.
DO NOT SCALE
REMOVE ALL BURRS & SHARP EDGES
ALTERATIONS
No | NOTE No. | ALTERATION | SIG: & DATE
1 | 1103 | 5·000 4·995 WAS 5·005 5·000 | G.G. 3.5.45
2 | 1517 | 1 3/8 WAS 1 7/16 | G.G 5.6.45
2- No. 6 B.A. HOLES ON 4 11/16 P.C. DIA.
TAP 5/32 DEEP, DRILL 5/16 DEEP
2- 1/4 B.S. FINE HOLES
TAP 3/8 DEEP, DRILL 1/2 DEEP
4- 1/4 B.S. FINE HOLES
ON 2·565 2·560 P.C. DIA.
3 1/4 DIA.
2 15/16 DIA.
2·0005 1·9995 DIA.
1/16 - 45°
1/4 R
1R
35°
3° DRAFT
5/8 DIA
(3 11/32)
5·000 4·995
ALL DIMENSIONS IN INCHES
FINISH: EXTERNAL SURFACES MADE SMOOTH AND FINISHED 1 COAT PRIMER, 1 COAT BRIGHT BLACK ENAMEL
LIMITS UNLESS STATED UNDER 1/2" ±0·010" OVER 1/2" BUT UNDER 1" ±0·015" OVER 1" ±0·025"
MACHINING SYMBOLS: ▽ MACHINE ROUGH MACHINE GRIND
DR'N A.B.
CH'D C.D.
P'D E.F.
DATE 1/1/45
SCALE 1/2
ALL THREADS B.S FREE FIT
MAT'L SPEC'N
FORM & TREATMENT SAND CORED DIECASTING
FINISH SEE ABOVE
PART NAME CASE
PART No. A.1012.
NAME OF FIRM

FIG. 71

store so that they can be easily traced should it be necessary to recall them.

Dimensioning. The method of fixing limits adopted for the detail drawings of the tachometer is for all working or mating surfaces to have limited dimensions and all non-mating surfaces to have limits based on the note printed on the drawing, which reads—

Dimension	Limit
$\frac{1}{2}$ in. and under	$\pm$ 0·010 in.
over $\frac{1}{2}$ in. and under 1 in. . . .	$\pm$ 0·015 in.
„ 1 in.	$\pm$ 0·025 in.

Clearance surfaces have the same limits as non-mating surfaces except in special cases.

Care should be taken that unintentionally large tolerances are not given to dimensions which have to be obtained by adding or subtracting other dimensions. For example, referring to Fig. 71, part A1012, the thickness of the base is given as $\frac{5}{32}$ in., which from the table is allowed a limit of $\pm$ 0·010 in., whereas had the depth $3\frac{11}{32}$ in., given in parenthesis, been put instead, the tolerance on the thickness would have been the sum of those on the $3\frac{11}{32}$ in., $1\frac{5}{8}$ in., and $1\frac{7}{8}$ in. dimensions, i.e. ($\pm$ 0·025 $\times$ 3) in., or $\pm$ 0·150 in.

Normally all dimensions are given so that the parts will be interchangeable, although it may be necessary to use a certain amount of selection when fitting the ball races to the shaft, as it is essential that these shall be a good press fit. Where parts have to be fitted in position, as is the case of the sleeve A1002 on the shaft A1001 (Fig. 69A), the part to be fitted should be shown chain dotted in position on the major component, and any necessary dimensions given. This will usually be found more convenient than putting the dimensions on the assembly drawing itself.

Adjustment. Where it is found that the limits necessary for the manufacturing processes are such that the parts when assembled will not function satisfactorily, and selection is out of the question, some means of adjustment must be provided. Several instances occur in the construction of the tachometer. The cap A1010 is ground when fitting the ball races to allow for variation in the lengths of the various parts. The tension

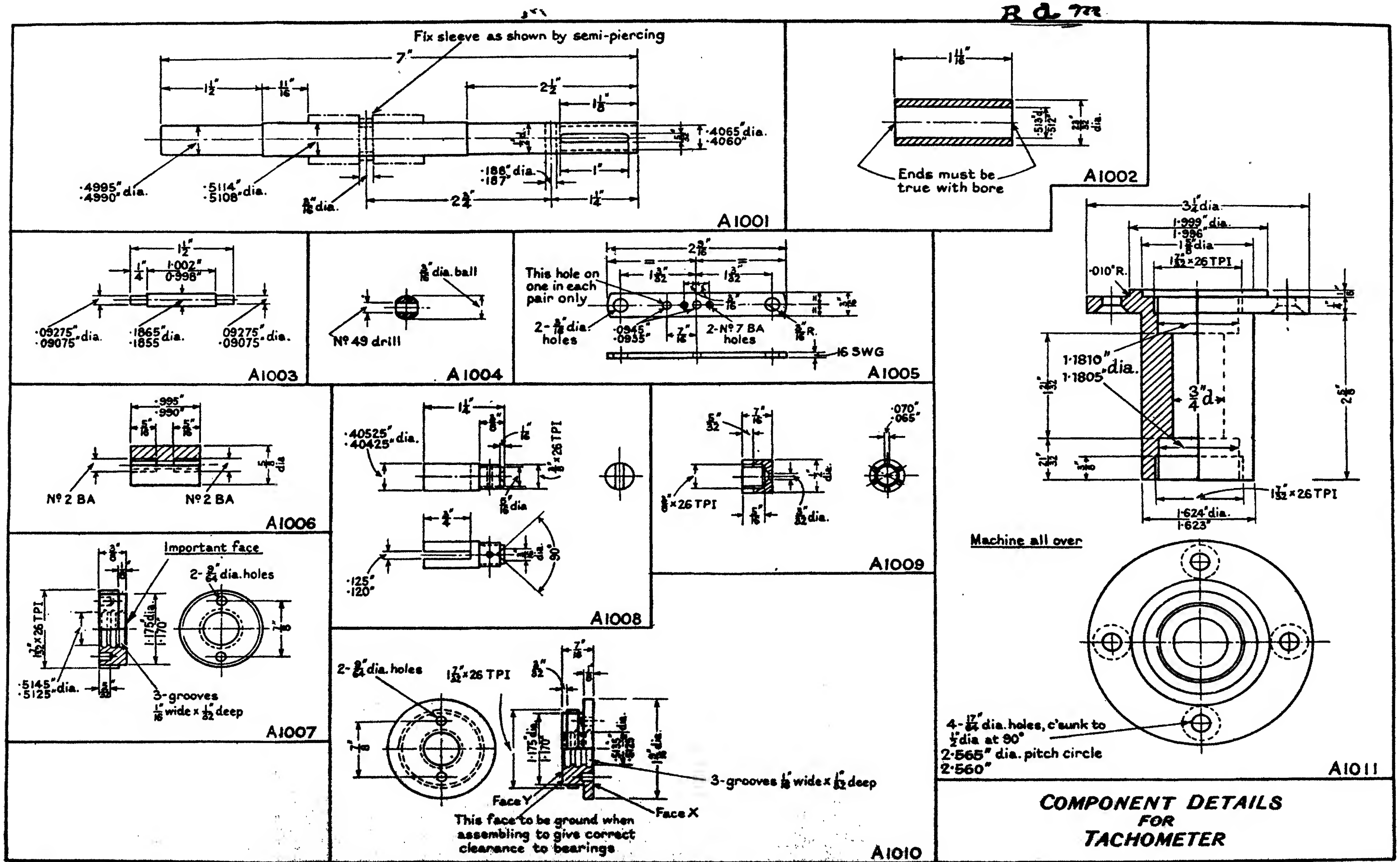
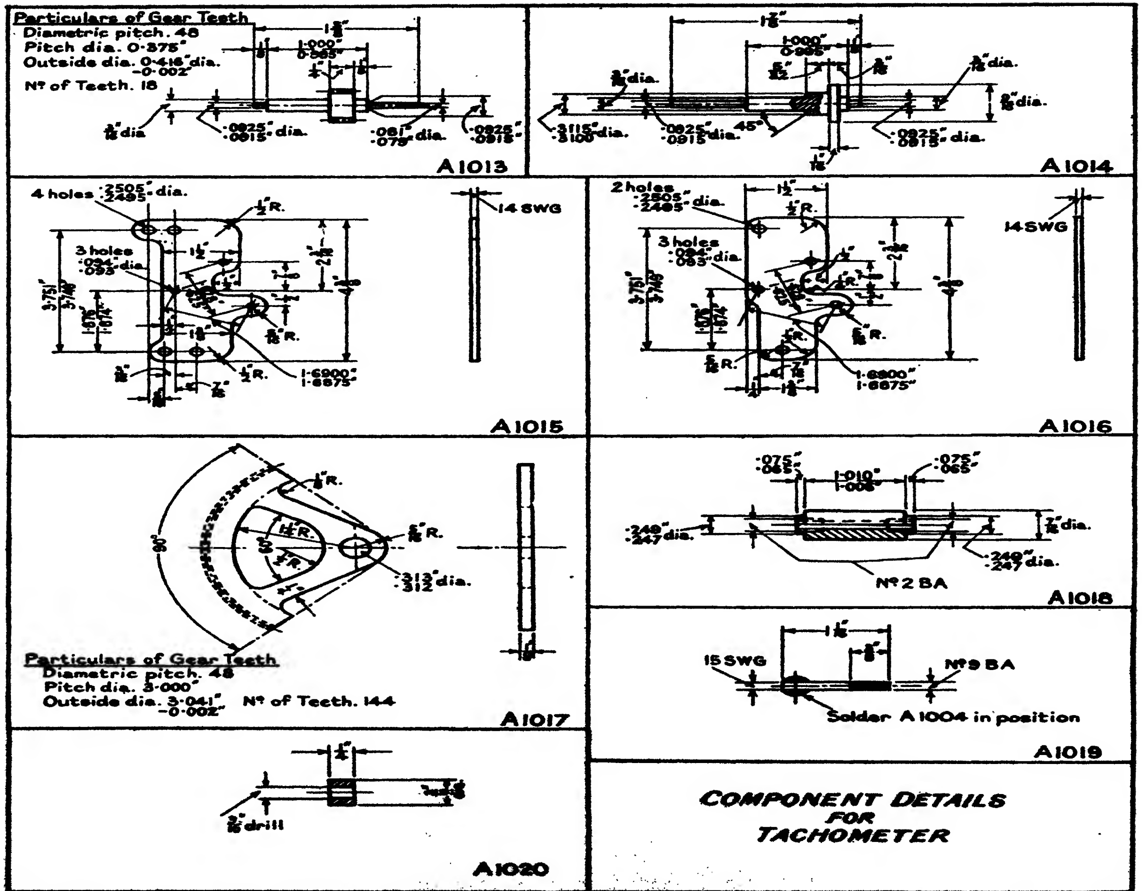

Fix sleeve as shown by semi-piercing
·4995" dia.
·4990"
·5114" dia.
·5108"
·4065" dia.
·4060"
·186" dia.
·187"
A1001
Ends must be true with bore
A1002
·09275" dia.
·09075"
·1865" dia.
·1855
1·002"
0·998"
A1003
№ 49 drill
A1004
This hole on one in each pair only
2-N° 7 BA holes
·0945"
·0935"
16 SWG
A1005
·995"
·950"
N° 2 BA
N° 2 BA
A1006
Important face
·5145" dia.
·5125"
3-grooves
1·175 dia.
1·170"
A1007
·40525" dia.
·40425"
·125"
·120"
90°
A1008
·070"
·065"
A1009
Face Y
Face X
This face to be ground when assembling to give correct clearance to bearings
A1010
·010" R.
1·999" dia.
1·996"
1·1810" dia.
1·1805"
Machine all over
2·565" dia. pitch circle
2·560"
1·624" dia.
1·623"
A1011
COMPONENT DETAILS
FOR
TACHOMETER

FIG. 69A



Particulars of Gear Teeth
Diametric pitch. 48
Pitch dia. 0·375"
Outside dia. 0·416" dia. −0·002"
Nº of Teeth. 18
A1013
A1014
4 holes ·2505" ·2495" dia.
3 holes ·094" ·093" dia.
14 SWG
1·6900" 1·6875"
A1015
2 holes ·2505" ·2495" dia.
A1016
Particulars of Gear Teeth
Diametric pitch. 48
Pitch dia. 3·000"
Outside dia. 3·041" −0·002"
Nº of Teeth. 144
·313" ·312" dia.
A1017
Nº 2 BA
A1018
15 SWG
Nº 9 BA
Solder A1004 in position
A1019
drill
A1020
COMPONENT DETAILS FOR TACHOMETER

(T. 96) FIG. [illegible]

of the springs A1025 may be adjusted by means of the plate A1024. Variations in the position of the spindle assembly and the movement are allowed for by the screwed rod A1027, which is locked by the nut A1029, when the correct setting is obtained.

Revision. It will be found that revisions have to be made to drawings quite frequently and for a variety of causes; improvements in manufacturing processes, experience gained in service, and mistakes are the most common causes. Once the alteration is decided on steps must be taken to inform all concerned immediately. This is best done by the Design Department issuing a note giving the details of the alteration, the effect on existing stocks, when it is to come into force and stating if the new part is interchangeable with the old. If interchangeability is affected then the part should be given a new number.

Description of Tachometer Details. The following gives particulars of the materials, heat treatment, and manufacturing operations for the components illustrated in Figs. 69A and 69B.

A1001. SPINDLE.

Material. Free cutting mild steel bought ground to 0·5128/0·5108 in. diameter.

Heat Treatment. None.

Operations.
1. Turn, drill, and ream right-hand end and cut off.
2. Centreless grind left-hand end.
3. Drill both holes.
4. Mill slot.
5. Centreless grind for ball races.
6. Remove all burrs.
7. Fit and fasten sleeve.

The material is obtained ground to a tolerance of 0·002 in., which is relatively inexpensive, and passed once through a centreless grinding machine to size it and remove burrs.

The $\frac{1}{2}$ in. diameter is turned to a limit of $\pm$ 0·002 in. to ensure it fitting in the jigs for the milling and drilling operation. This would be shown on the inter-operation drawing.

The sleeve is fastened in position by a special tool which raises two dowels into the hole in the spindle.

*A*1003. Sleeve

Material. Free cutting mild steel.
Heat Treatment. None.
Operations. 1. Drill and ream hole and cut off.
2. Face end true and remove burr from hole.

It is essential that both ends should be true with the bore for the ball race to seat correctly. This fact should be noted on the drawing or specification.

*A*1001. Pendulum Spindle

Material. Free cutting mild steel.
Heat Treatment. Caseharden in cyanide about 0·003 in. deep.
Operations. 1. Turn all over in automatic lathe leaving a slight chamfer on both ends to ensure absense of burr.
2. Centreless grind 0·1865/0·1855 in. diameter.
3. Cyanide harden.

The grinding operation is more economical than attempting to turn to the limits given on large diameter.

*A*1004. Ball

Material. $\frac{3}{16}$ in. diameter standard ball bearing.
Heat Treatment. As below.
Operations. 1. Anneal by heating for one hour at 850° C. in carefully sealed pot to exclude air, and allowing to cool slowly in a warm, draughtless place.
2. Drill hole for wire.
3. Harden at 800–825° C. and quench in oil.
4. Temper at 200° C.
5. Polish by barrelling in sawdust.

*A*1005. Pendulum Arm

Material. Hard brass strip (approx. analysis 63 per cent Cu, 1 per cent Pb, remainder Zn) $\frac{3}{16}$ in. wide by 16 S.W.G. by 6 ft. long.
Operations. 1. Crop off strip.
2. Drill all holes.
3. Ream.
4. Tap holes.

The ends are made with the large radius shown instead of semicircular, to simplify the cropping operation, there being a certain amount of difficulty in producing an end of the latter shape. Drilling is used instead of piercing as it is the most economical for the quantities to be manufactured.

*A*1006. PENDULUM WEIGHT

Material. Free cutting brass.

Operations. 1. Drill right through and tap one end. Turn small chamfer on each end to remove burrs. Cut off.
2. Tap other end.

*A*1007. CAP

Material. Free cutting brass.

Operations. 1. Turn outside and cut thread. Drill hole, turn grease retaining grooves and reamer. Cut off.
2. Drill holes for pin spanner.
3. Remove burr from hole.

It is important that the thread, bore, and inside end should be true with each other and they must, therefore, be turned at the same operation. The outer face need not be true in this case and therefore no separate facing operation is necessary as was the case with A1002.

*A*1008. PISTON

Material. Free cutting mild steel.

Heat Treatment. Caseharden in cyanide about 0·003 in. deep.

Operations. 1. Turn to 0·409/0·406 diameter, screw, form ball seating and cut off, leaving slight chamfer on rear end.
2. Mill slot.
3. Drill hole locating from slot.
4. Centreless grind outside.
5. Cyanide harden.

The 0·409/0·406 diameter would be shown on the inter-operation drawing. Note the small amount of material left to be removed by grinding.

*A*1009. PISTON CAP

Material. Free cutting mild steel.

Heat Treatment. Caseharden in cyanide about 0·003 in. deep.

Operations. 1. Drill holes and tap. Cut off.
2. Remove burr from hole.
3. Mill slots.
4. Cyanide harden.

The six slots are provided to enable the parts to be screwed up to give the correct amount of freedom to the ball joint, and then secure by a split pin.

*A*1010. Cap

Material. Free cutting mild steel.

Heat Treatment. None.

Operations. 1. Turn for thread, screw, drill, turn grease retaining grooves and cut off.
2. Drill holes for pin spanner.
3. Grind face *X* true with face *Y*, with the part held in a magnetic chuck.

As for A1007, the bore, thread and front face must be true. About 0·020 in. is left on face *Y* so that adjustment can be made when fitting the ball races to give the correct amount of play.

The part is made of steel so that it may be held in a magnetic chuck for grinding, which would, of course, be impossible if it were of brass.

The face *X* is ground true with face *Y* and therefore true with the thread and bore, so that when face *Y* is ground it will also be true.

*A*1011. Shank

Material. Cast iron. Approximate composition 3·45 per cent C, 1·8 per cent Si, 0·55 per cent Mn. Brinell 160–210.

Operations. 1. Hold by $3\frac{1}{4}$ in. diameter in a chuck and turn stem to 1·635/1·630 in. diameter, face flange and end. Drill $\frac{3}{4}$ in. diameter hole and ream to 0·751/0·749 in. diameter. Bore out for race, tap, first and second ream to size for race. (See Fig. 73).
2. Screw on to special snug locating on 0·751/0·749 in. reamed hole. Face end, turn, register, bore out for race, tap, and first and second ream for race.
3. Grind shank to size.
4. Drill and countersink holes.

It will be noticed that considerable care must be taken to ensure that the ball race housings are accurate and in line with each other. The tolerance allowed on the register (1·999/1·996 in.) makes it possible to machine it without the necessity of a subsequent grinding operation.

*A*1012. CASE

Material. Aluminium die casting (4L11 Alloy).

Operations. 1. Face and bore out to take A1011.
2. Drill and tap holes for fixing A1011.
3. Drill and tap holes for fixing movement and face bosses.
4. Drill and tap holes for bezel.
5. Drill and tap holes for dial.
6. Black enamel.

The casting for this part is made in a metal die with a sand core. This has the advantage of greatly cheapening the cost of the die whilst giving, for this purpose, an equally efficient article, only two machining operations, with the exception of the drilling and tapping of holes, being necessary.

*A*1013. PINION

Material. Stainless iron (14 per cent Cr, 0·1 per cent C) bought in fully heat-treated condition.

Operations. 1. Turn all over on automatic lathe.
2. Cut gear teeth on hobbing machine.
3. Burnish bearings between hardened steel rollers.

Although working conditions for this part are not severe and there is no general corrosion, it is found that the teeth corrode at the point of contact after the instrument has been running for some time, causing inaccuracies, but the use of stainless iron prevents this. Burnishing the bearing surfaces reduces friction, and gives a longer bearing life.

*A*1014. AXLE

Material. Free cutting mild steel.

Heat Treatment. None.

Operations. 1. Turn all over on automatic lathe.
2. Burnish bearings.

The 0·3115/0·310 in. diameter is undercut to facilitate riveting to A1017.

*A*1015 *and* *A*1016. Side Plates

Material. Hard brass sheet. 63/37 type with 1 per cent lead.
Operations. 1. Blank out to shape with press tools.
2. Drill all holes.
3. Remove burr from both sides of all holes with special cutter.
4. Ream holes to size.

The same remarks apply here as to A1005 in regard to economy of drilling.

*A*1017. Quadrant

Material. Hard brass sheet 63/37 type with 1 per cent lead.
Operations. 1. Blank out to shape with press tools.
2. Pierce lightening hole.
3. Pierce hole for A1014.
4. Ream hole.
5. Cut gear teeth on hobbing machine.

*A*1018. Pillar

Material. Free cutting brass.
Operations. 1. Drill hole right through and tap one end. Turn two necks together, 0·249/0·247 in. diameter, to ensure 1·010/1·005 in. dimension being correct.
2. Tap hole other end and face end to correct length.

*A*1019. Ball Rod

Material. 15 S.W.G. Hard Drawn Mild Steel Wire.
Heat Treatment. None.
Operations. 1. Screw end and cut off.
2. Fit ball on end and solder in position.
3. Remove any surplus solder.

Specifications. Although specifications for individual parts or complete products are seldom necessary when they are manufactured entirely in one factory, they are particularly useful when parts are to be purchased from outside sources.

It is advisable in such cases that the specifications should

SPECIFICATION

Part No.	A1012.
Name.	Case for 5 in. Tachometer.
Material.	Sand-cored Aluminium Diecasting to B.S.S. 4L11. $\frac{1}{32}$ in. to be left on surfaces marked ∇. Tapped holes not cast in.
Machining.	Machine where marked ∇ on drawing. Machined surfaces to be true with 5 in. diameter rim and each other.
Finish.	External surfaces to be filed smooth before enamelling. Spray with one coat primer and one coat Light Shot Blast, Messrs. Smiths' No. 999 Black Lacquer and stove after each coat for two hours at 150° C.

Fig. 72. Specification for Case

state clearly what tests will be applied by the buyer, and any information which it is considered necessary to have in order to ensure a product of the desired quality being obtained.

Specifications of complete products, not designed by the purchaser, should only include the essentials which affect the user and should not be concerned with minute constructional details. For instance, if an engine builder wished to purchase tachometers, his specification should include the following—

1. Size of dial.
2. Markings on dial, i.e. range of speed, wording, etc.
3. Accuracy.

4. Size and length of shanks.
5. Size and length of spindle.

In other cases, it might be stipulated that certain parts, known to wear out in service, should be interchangeable and readily replaceable.

In the event of a specification being prepared for a complete assembly designed by the purchaser, it may be necessary to

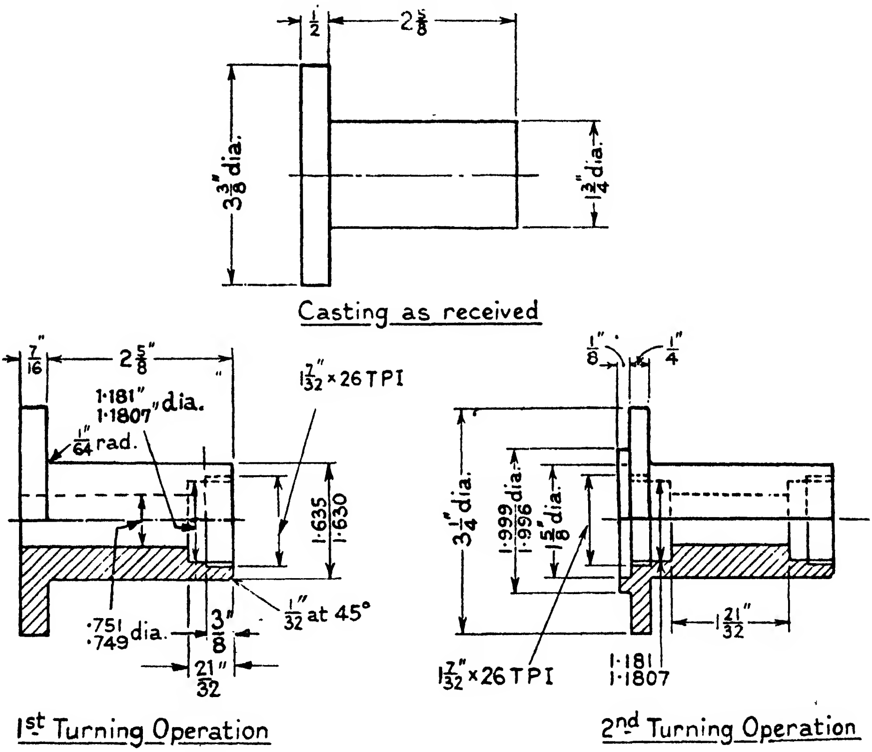


FIG. 73. INTEROPERATION DRAWINGS FOR SHANK

go into the matter in some detail. The practice is sometimes adopted of making up a sample mechanism and using this as a basis of comparison, but this is dangerous, as it is quite possible for important points to be overlooked, whilst with a written specification, emphasis can be laid on the essential features.

Specifications for component parts are intended to amplify the detail drawings and it is a difficult question to decide what information should appear on the specification and what on the drawing. If the specification is at all comprehensive, it is

advisable to confine the drawing to giving dimensions only, all other particulars being included in the specification. A specification for the case of the tachometer suitable for issuing to a firm who were to supply the parts completely finished is given in Fig. 72.

Interoperation Drawings of Components. These are simply drawings showing the component in a partly finished state for the guidance of the operators. They are made in consultation with the Production Department and show the shape of the part as it appears after each operation is finished and the dimensions relevant to that operation. A series of operation drawings for the shank A1011 is given in Fig. 73.

APPENDIX

TABULATED DATA

TABLE I
MODULI OF ELASTICITY AND RIGIDITY

Material	Modulus of Elasticity (lb. per in.^{2})	Modulus of Rigidity (lb. per in.^{2})
Aluminium	10×10^6	4×10^6
Brass	15×10^6	6×10^6
Cast iron	12×10^6	—
Monel	25×10^6	9×10^6
Steel	30×10^6	12×10^6
Zinc	13×10^6	5×10^6

TABLE II
LIMITS ON EXTRUDED AND DRAWN BRASS BARS

Size of Bar (in.)	Limits of Accuracy	
	Extruded	Drawn
Up to $\frac{7}{16}$	± 2	$+0 \quad -2$
$\frac{1}{2}$ to $\frac{7}{8}$	± 3	$+0 \quad -3$
1 to $1\frac{3}{8}$	± 4	$+0 \quad -3$
$1\frac{1}{2}$ to $1\frac{3}{4}$	± 5	$+0 \quad -4$
$1\frac{7}{8}$ to 2	± 6	$+0 \quad -4$

Limits in 0·001 in. for diameter or width of extruded and drawn brass bar

TABLE III
LIMITS ON COLD-ROLLED BRASS SHEET
(B.S.S. 266)

Thickness (in.)	Width (in.)			
	Up to 6	6 to 12	12 to 24	24 to 36
Up to 0·010	$\frac{1}{2}$	1	$1\frac{1}{2}$	—
0·011 to 0·024	1	$1\frac{1}{2}$	2	$2\frac{1}{2}$
0·025 to 0·040	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3
0·041 to 0·080	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$
0·081 to 0·128	2	$2\frac{1}{2}$	$3\frac{1}{2}$	4
0·129 to 0·252	$2\frac{1}{2}$	3	4	5

Limits above and below nominal size in 0·001 in. for thickness of sheet brass.

TABLE IV

MATERIALS

Irons

Grey Cast Irons

Constituents (other than Fe) per Cent					Tensile Strength (tons per in.^{2})	Brinell Hard-ness	Remarks
C	Si	Mn	S	P			
2·9–3·1	3·0–3·2	0·5–0·6	0·1 max.	1·0–1·3	9–12	190–240	For rapid machining Light castings
3·2–3·4	1·7–1·9	0·5–0·6	0·1 max.	0·5–0·7	11–14	160–210	General castings over ½ in. thick
3·2–3·9	1·6–1·8	0·6–0·7	0·1 max.	0·15–0·9	11–18	230	For wear and pressure resistance

Alloy Cast Irons

Constituents (other than Fe) per Cent				Tensile Strength (tons per in.^{2})	Brinell Hard-ness	Remarks
C	Si	Mn	Alloy			
3·25	2·0	0·7	2 Ni	18	220	Close grained for cylinders, etc. Machines well
3·0–3·2	1·8–2·0	0·7	1·5 Ni 0·3 Cr	20	350	For gears, cams, etc. Hardened at 800° C. and tempered at 350° C.
1·5	1·0	0·7	0·5 Cr 1·75 Cu	—	280 400 (chilled)	Camshafts and crankshafts (generally heat-treated)

Malleable Cast Iron

British Standard Specification Nos.	Tensile Strength (tons per in.^{2})	Minimum Elongation (% on 2 in.)	Remarks
309	20	5	Small castings subject to shock
310	20	7·5	

TABLE IV—(*Contd.*)

Class	B.S. 970	Constituents (other than Fe) per Cent					Tensile Strength Tons per in.^{2}			Izod Test (Ft.-lb.)	Elongation (% on 2 in.)
		C	Mn	Ni	Cr	Mo	$1\frac{1}{8}$ in. dia.	$2\frac{1}{2}$ in. dia.	4 in. dia.		
Carbon Steels											
Free Cutting	En 1	.2 max.		.25 Sulphur			25				
Do. for Casehardening	En 1A	.15 max.			Do.		25				
Mild Steel for Machining	En 2	.2					28–35	28–38*			25–15
,, for Cold Forming	En 2A	.2 max.					26				
"40" Carbon (as Rolled)	En 8	.4	1.5				35–45			10 min.	20 min.
,, (Hardened and Tempered)	En 12	.4	1.5				40 min.	40	40	25–35	22 min.
"55" Carbon	En 9	.55	·7				45–65				18–12·5
Casehardening	En 32	·21 max.	·7				32 min.			40 min.	20 min.
Alloy Steels											
Manganese Casehardening	En 20	·18 max.	1·5				40			40 min.	20 min.
3% Nickel Casehardening	En 33	·16 max.	·4	3·0			45			40 min.	18 min.
3% Nickel Chrome Casehardening	En 36	·18 max.	·4	3·4	·8		55–80			35–30	15–13
Manganese-Nickel Molybdenum	En 13	·2	1·6	·55		·25	40	40	40	40 min.	22 min.

Carbon-Manganese . . .	En 15	·35	1·5				50	45	40	35–30	22–20
Manganese Molybdenum . . .	En 17	·35	1·5			·45	65	60	55	40–35	18–16
1% Chromium	En 18	·4	·9		1·0		55	50	45	40 min.	22–18
1½% Nickel-Chromium-Molybdenum .	En 24	·4	·65	1·5	1·6	·3	100	65	60	35–8	16–8
2½% Nickel-Chromium-Molybdenum .	En 26	·4	·6	2·5	·65	·55			100	10 min.	10 min.
4¼% Nickel-Chromium . . .	En 30	·4	·5	4·25	1·25		100 air h'd		100 oil h'd	10 min.	10 min.

* These figures obtained by increasing carbon to ·3%.

TABLE IV—(*Contd.*)

Spring Steels—Wire and Strip

Class	British Standard Specification No.	Constituents (other than Fe) per Cent		Remarks
		C	Others	
		Wire		
Hard-drawn Wire $\frac{3}{16}$ in. dia. and under	—	0·45	—	100–200 tons per in.^{2} Tensile strength depending on size
Hard-drawn Wire over $\frac{3}{16}$ in. dia.	—	0·7	—	
Hardened and Tempered Wire and Strip $\frac{3}{16}$ in. and under	—	0·45	—	Tempered as required
Hardened and Tempered Wire and Strip over $\frac{3}{16}$ in.	—	0·7	—	Do.
Carbon Steel Oil-hardening $\frac{3}{16}$ in. dia. and under	—	0·45	—	Hardened and tempered to 40–45 Rockwell C scale
Carbon Steel Oil-hardening over $\frac{3}{16}$ in. dia.	—	0·7	—	Do.
Cr-Va Oil-hardening	En. 47	0·5	Cr 1·0	
	—	—	Va 0·15	
Si-Mn Oil-hardening	—	0·5	Si 2·0	
	—	—	Mn 1·0	

Strip and Sheet Carbon Steels				
Mild Strip, Cold Rolled	5006/207	0·2 max.	—	For tempers, see page 23
Mild Sheet, Cold Rolled, Close Annealed	5007/214	0·2 max.	—	Supplied in softened condition only
Mild Sheet, Hot Rolled and Normalized	5007/215	0·15–0·13	—	Must withstand 180° bend round radius = ½ thickness 26 tons per in.², min.
Strip and Sheet Alloy Steels				
Nickel Sheet, Hot Rolled and Normalized	5007/405	0·2 –0·3 Ni	2·5–3·5	35 tons per in.², min.; 180° bend round radius = ¾ thickness

Notes

C = Carbon Si = Silicon Mn = Manganese Mo = Molybdenum
Ni = Nickel Cr = Chromium Va = Vanadium

For further information regarding En series will be found in British Standard Schedule 970.

The Chemical Compositions are nominal only.

TABLE IV—(*Contd.*)

ALUMINIUM AND ALUMINIUM ALLOYS

Class	Designation	Condition	Tensile Strength (Tons per in.^{2})	Elongation (per Cent on 2 in.)	Brinell Hardness	Forms	Remarks and Uses
Pure Alum. (99%)	2L4	H.	9 min.	8–2	40–50	Sheet	Food utensils, and low stress pressings
Do.	2L16	H.H.	7–8½	12–5	23–40	Do.	
Do.	2L17	S.	5–6½	12 min.	19–23	Do.	
Do.	,,	S.	5–6	12 min.	19–23	Sections	Ornamental
Screwing	BA–35	—	—	—	—	Do.	Turned parts
Alum-Silicon	BA–40D	H.	12–14	9–5	—	Sheet	Pressings
Do.	Do.	H.H.	10–12	15–10	—	Do.	Do.
Do.	Do.	S.	9–10	30–20	—	Do.	Do.
Alum-Manganese	BA–60A	H.	14–17	5–3	—	Do.	Pressings resistant to corrosion
Do.	,,	H.H.	9–11	11–7	—	Do.	
The above may be annealed by heating to 350° C. and quenching in water. Can be hardened by cold work only.							
Al-Zn-Cu Alloy	3L5	S.C.	10	3	60	S.C.	Usual casting alloy in Great Britain
Al-Cu Alloy	4L11	S.C.	8	2	60	S.C.	Widely used for die castings
Do.	Do.	D.C.	10	4	65	D.C.	
Al-High Si	BA–40D	S.C.	11	7	55	S.C.	Resistant to corrosion and shock
Do.	Do.	D.C.	14	10	60	D.C.	
Al-Medium Si	BA–40J	S.C.	10	8	47	S.C.	Cheaper than BA–40D
Do.	Do.	D.C.	12	17	50	D.C.	
Al-Cu-Si	BA–37	S.C.	9	3	60	S.C.	Difficult castings
Do.	Do.	D.C.	12	7	60	D.C.	

The above are used as cast and without heat treatment.

Duralumin	—	H.T.	25	20	90–100	Sheet sections forgings	Strength approximates to that of mild steel
"Y" Alloy	—	S.C.	16	1·5	100	S.C.	Strength at high temperatures. High thermal conductivity
Do.	—	D.C.	20	3·0	105	—	
Do.	—	F.	25	22	100	—	
Al-Si-Mg	BA–40/M	S.C.	18	1	100	S.C.	Complicated and strong castings
	—	D.C.	22	1·5	110	D.C.	
Dural H	—	H.T.	20–24	15–10	100	Sheet sections forgings	High elect. conductivity Resistant to corrosion
Hiduminium	RR50	S.C.	11	3	72	S.C.	Highly-stressed castings
	Do.	D.C.	16	4–8	80	D.C.	
	RR53	D.C.	24	1	140	D.C.	For pistons
	RR56	F.	30	15	140	Forgings	High stresses
	RR59	F.	24	8	130	Do.	For pistons

The above alloys are heat-treated before use.
Test Figures given are after heat treatment.

H. = Hard
H.H. = Half Hard

S. = Soft
H.T. = Heat-treated

S.C. = Sand Cast
D C. = Die Cast

F. = Forging

TABLE IV—(*Contd.*)

BRASS AND COPPER ALLOYS

Class	British Standard Specification No.	Constituents per Cent			Tensile Strength (Ton per in.²)	Elongation (Percentage on 2 in.)	Forms	Remarks and Uses
		Cu	Other	Zn				
Gilding Metal	—	90	—		—	—	Sheet and tube	Ornamental
Cartridge Brass	267	70	—		35–19	10–70	Sheet, wire and tube	Deep drawn parts
65/35 Brass	266	65	—		30–18	5–35	Do.	Raised parts
Basis Brass	265	61·5–64	—		30–18	5–35	Sheet	Plain pressings
Yellow Metal	—	60	—		25–28	45–35	Sections, hot stampings and sand castings	Machined parts to be bent or riveted
Riveting Free Cutting Brass	—	62–64	1 Pb	Remainder	23–25	40–30	Sections and sheet	Machined parts to be riveted Simple pressings to be machined
Free Cutting Brass (Recommended)	—	60–62	2–3 Pb.		23–25	30–20	Sections	Machined parts
Free Cutting Brass	218	58	2 Pb		26–28	20–15	Sections, hot stampings and castings	Do.

High Tensile Brass	250/A	58	Various	Remainder	30 min.	25 min.	Do.	Misc. parts
Do.	250/B	58	Do.	Do.	35 min.	20 min.	Do.	Do.
Aluminium Bronze	—	90	10 Al	—	30–35	30–25	Sections and castings	Corrosion resisting
Phosphor Bronze	384	97–93	3–7 Sn	—	25–50	—	Sheet and wire	Springs. Composition and temper depends on design
Do.	B8	89	10 Sn, 1 P	—	—	—	Castings	Bearings
Gunmetal	—	88	10 Sn	2	—	—		
Nickel Silver	—	60–65	10 Ni	Remainder	25–50	50–5	Sheet, sections, castings, and stampings	White colour Corrosion resisting
	—	Do.	12 Ni	Do.	Do.	Do.		
	—	Do.	15 Ni	Do.	Do.	Do.		
	—	Do.	18 Ni	Do.	Do.	Do.	Sheet and castings	
	—	Do.	20 Ni	Do.	Do.	Do.		
Cupro-Nickel	—	80	25 Ni	—	20–30	40–6	Wire, sheet and tubes	White colour
	—	75	25 Ni	—	Do.	Do.		Ductile
	—	70	30 Ni	—	Do.	Do.		Corrosion resisting
Monel	—	30	70 Ni	—	30–45	30–18	Cold worked sheet, sections and wire	Exacting conditions of heat and corrosion
Zinc Die-casting: Alloy A	1003/4	—	4 Al	Remainder	19–23 18	12 6–4	Castings Die castings	Dimensionally stable
Do. Alloy B	,,	0·75/1·25	—	—	23	—	,,	General use

TABLE V

Machining Tolerances

Process	Tolerances (in.)		
	Normal	With Care	Smallest Economical
Turning, diameters	0·008	0·004	0·001
Turning with roller box tool, diam.	0·005	0·002	0·001
Turning, lengths	0·015	0·006	0·003
Boring	0·005	0·002	0·0005
Drilling	0·005 above size of drill		
Reaming up to $\frac{1}{4}$ in.	± 0·0006	± 0·0003	
„ $\frac{5}{16}$ in. to $\frac{1}{2}$ in.	± 0·0008	± 0·0004	
„ $\frac{9}{16}$ in. to $\frac{15}{16}$ in.	± 0·001	± 0·0005	
„ 1 in. to $1\frac{7}{16}$ in.	± 0·0012	± 0·0006	
Milling, distance between two faces	0·010	0·005	0·002
Milling, lengths of slots, etc.	0·030	0·015	0·005
Broaching	0·005	0·002	0·001
Surface grinding	As required	0·002	0·001
Cylindrical grinding	Do.	0·001	0·0003
Honing	Do.	0·0005	0·00025
Diamond boring	Do.	0·001	0·00025
Lapping	Do.	0·00025	0·0001 and finer
Centre, distance of holes, etc.	0·005	0·002	0·0005
Press work (tolerances depend on design of part)	0·005	0·001	0·0005
Die castings, Mouldings and Hot Stampings—			
Across parting line	0·010–0·015	0·010	0·005
Not across parting line	0·005–0·010	0·005	0·0025

TABLE VI

Second-class Running Fits

Size (in.)	Limits (in.)	
	Holes	Shafts
Up to $\frac{1}{4}$	$\pm$ 0·0006	− 0·0016 to − 0·0036
$\frac{5}{16}$ to $\frac{9}{16}$	$\pm$ 0·0008	− 0·0018 to − 0·0038
$\frac{5}{8}$ to $\frac{15}{16}$	$\pm$ 0·001	− 0·002 to − 0·0045
1 to $1\frac{7}{16}$	$\pm$ 0·0012	− 0·0022 to − 0·0052
$1\frac{1}{2}$ to 2	$\pm$ 0·0014	− 0·0024 to − 0·006

Note. Holes finished with reamers made to B.S. 122.

TABLE VII

Light Interference Fits

(The Hoffmann Mfg. Co. Ltd.)

Size (in.)	Limits (in.)	
	Race	Housing
Up to 2	− 0·0003 to − 0·0008	− 0·0005 to − 0·001
2 up to 3	− 0·0005 to − 0·001	− 0·0007 to − 0·0012
3 up to 5	− 0·0008 to − 0·0013	− 0·001 to − 0·0015

TABLE VIII

Tapping Drill Sizes

Thread	Tapping Drill	Thread	Tapping Drill
$\frac{1}{4}''$ B.S. Fine	No 4 (·209″)	No. 0 B.A.	No. 7 (·201″)
$\frac{5}{16}''$,,	$\frac{17}{64}''$	No. 2 ,,	No. 22 (·157″)
$\frac{3}{8}''$,,	$\frac{21}{64}''$	No. 4 ,,	No. 32 (·116″)
$\frac{7}{16}''$,,	Letter V (·377″)	No. 6 ,,	No. 42 (·093″)
$\frac{1}{2}''$,,	$\frac{7}{16}''$	$\frac{1}{8}''$ B.S. Pipe	$\frac{11}{32}''$
$\frac{5}{8}''$,,	$\frac{35}{64}''$	$\frac{1}{4}''$,,	$\frac{15}{32}''$
$\frac{3}{4}''$,,	$\frac{4}{64}''$	$\frac{3}{8}''$,,	$\frac{39}{64}''$
		$\frac{1}{2}''$,,	$\frac{3}{4}''$
		$\frac{3}{4}''$,,	$\frac{31}{32}''$

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